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Laurence J. Bement,
Eleonore G. Kayser,
and Morry L. Schimmel

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Service Life Evaluation of Rigid Explosive Transfer Lines

Laurence J. Bement
Langley Research Center
Hampton, Virginia

Eleonore G. Kayser
Naval Surface Weapons Center - White Oak
Silver Spring, Maryland

Morry L. Schimmel
McDonnell Aircraft Company
St. Louis, Missouri

National Aeronautics and Space Administration

Scientific and Technical Information Branch

PREFACE

The explosive materials hexanitrostilbene (HNS) and dipicramide (DIPAM) used in explosive transfer lines were synthesized at the Naval Surface Weapons Center (NSWC), White Oak, Silver Spring, Maryland, in the early 1960's. NSWC has had continuous responsibility for chemical synthesis development and generation of military specifications. NSWC accomplished initial production, made the first applications, and supported all subsequent applications.

The initial aircraft application of rigid explosive transfer lines using HNS and DIPAM was on the F-111 crew module, developed in the mid-1960's. The system was designed by McDonnell Aircraft Company, St. Louis, Missouri.

The original concept of using the approach described in this report for extending the service life of rigid explosive transfer lines was funded by the B-1 Project, Wright Patterson AFB, Ohio, and contracted to McDonnell Aircraft Company, through Calspan Purchase Order 25996, "Pyrotechnic Service Life Test Plan for B-1 Aircraft," January 25, 1977.

The funding for the program described in this paper was provided by the U.S. Army Aviation Research and Development Command (AVRADCOM), St. Louis, Missouri, and the Helicopter and Powered Lift Technology Division, NASA Ames Research Center. The program was managed by the Systems Engineering Division, NASA Langley Research Center.

The technical tasks were accomplished as follows. NASA Langley Research Center developed and conducted the performance tests and provided the final documentation. NSWC developed and performed the chemical analyses and photographic tests, and McDonnell Aircraft Company provided technical consultation.

SUMMARY

A service life evaluation program was conducted on rigid explosive transfer lines used to initiate aircraft emergency crew escape functions for a wide variety of military and NASA aircraft. The purpose was to determine quantitatively the effects of service, age, and degradation on rigid explosive transfer lines to allow responsible, conservative, service life determinations. The technical approach was to develop a test methodology, test the three types of transfer lines in use in the U.S. (including lines with no service and also lines removed after rated service from five military aircraft models), test these lines following a repeat of the original thermal qualification tests, and conduct a degradation investigation. The 800 rigid explosive transfer lines tested were not adversely affected by age (up to 10 years), service (up to 7 years), or a repeat of the thermal qualification tests on full-service lines. Explosive degradation limits were approximated, degradation changes were observed, and mechanisms were proposed. Extension of the service life of rigid explosive transfer lines should be considered, since considerable cost savings could be realized with no measurable decrease in system reliability.

INTRODUCTION

Extending the service life of rigid explosive transfer lines used to initiate and sequence aircraft emergency crew escape systems provides an opportunity for considerable savings for a variety of military and NASA aircraft. The rated service life of explosive components for aircraft crew escape has been established on a necessarily conservative basis, with an equally cautious attitude toward service life extensions. Past service life surveillance programs have relied on test methods that have provided limited information to establish the functional status of transfer lines having full service and to project further service extensions. The purpose of the effort described in this paper was to determine quantitatively the effects of service, age, and degradation on rigid explosive transfer lines to allow responsible, conservative service life determinations.

Rigid explosive transfer lines, commonly called shielded mild detonating cord (SMDC), are designed to transfer a fully contained explosive stimulus and are the most extensively applied components in aircraft crew escape systems. Explosive transfer lines utilize mild detonating cords, which consist of tubes containing very small quantities of highly stable explosives in a metal sheath. This cord is centered by a plastic extrusion in a 0.19-in-diameter steel tube, which provides containment of explosive products. Transfer lines interconnect the components for aircraft emergency functions in a manner similar to high-pressure tubing. Event sequencing is accomplished by in-line time delay (slow-burning fuse) elements. More than 1 million rigid explosive transfer lines have been manufactured for application in such aircraft as the Army AH-1, NASA/Army Rotor Systems Research Aircraft (RSRA), NASA Space Shuttle, the Air Force F-111, F-15, F-16, and B-1, and the Navy EA-6, S-3A, F-14, and F-18.

The establishment of the rated service life for explosive transfer lines has been approached on a conservative basis because of the human-life-critical function they perform. The concept of the unstable nature of explosives was extrapolated to the materials used in transfer lines, and, consequently, a relatively short service life was originally established. Furthermore, little technology exchange on service life has occurred among the various aircraft programs; as of 1981, the rated service life of rigid explosive transfer lines typically ranged from 3 years on the B-1 to 15 years on the F-16, with the rated service life of most aircraft systems established at 5 years for essentially the same transfer line materials and design.

All explosive transfer lines on military aircraft, as of 1981, were scheduled for removal and replacement (changeout) on completion of rated service life. Changeout costs include removal of the aircraft from service, transfer of the aircraft to and from refurbishment sites, procurement of replacement components, and labor. Changeout often requires removing large sections of the airplane. For example, approximately 600 man-hours are required to remove the nose section of the F-14 and to replace approximately 150 explosive transfer lines. Approximately 40 000 man-hours are required to de-mate the B-1 crew module and to replace the escape system, which includes 1200 transfer lines.

To reduce these program costs, a number of transfer line service life extension (surveillance) programs are being conducted. Rigid transfer lines (1) have a long history of successful performance, (2) have a rugged, hermetically sealed assembly, and (3) contain only thermally stable high explosives. However, no acceptable method such as elevated-temperature "accelerated aging" (ref. 1) has been developed and substantiated to predict reliably service life limits for explosive components of this type. The approach used by the past surveillance programs was to remove and replace transfer lines on completion of rated service. The removed lines were examined visually and by X-ray and subjected to a repeat of all, or a portion of, the initial lot acceptance and qualification testing. The lines were then functionally tested. Prior to the effort described in this paper, functional testing was primarily on a "go/no-go" basis. That is, the line did or did not function.

"Go/no-go" testing provides little information on the actual functional status of explosive transfer lines. If the line functioned, how well did it perform, or was there any change? Can service life be extended, and if so, for how long? If the line failed to function, how, where within the line, and when did it fail? Was the failure caused by a previously undetected design weakness, by improper installation, by service, or by the removal process?

More detailed information on the functional status of explosive transfer lines before and after service could increase confidence in system design and qualification, reduce the concern and risk in extending service, and improve aircraft emergency system reliability by avoiding too frequent teardown and replacement of transfer lines, with the accompanying potential of damage and improper assembly.

To provide this information, more than 800 rigid explosive transfer lines were removed from AH-1G, AH-1S, F-111, B-1, and F-14 aircraft and evaluated after rated service. Seven-year-old B-1 lines with no service were also evaluated. These transfer lines represent all three explosive cord types and all three manufacturing methods in use in the U.S. The cord types are silver-sheathed recrystallized hexanitrostilbene (HNS-II), aluminum-sheathed HNS-II, and silver-sheathed dipicramide (DIPAM). The three manufacturing methods used to make the explosive cords are (1) swage/hammering of fully annealed tubes, (2) swage/hammering of work-hardened tubes, with three 425°F, 1-hr annealing cycles, and (3) pultrusion.

The technical approach for this program was to establish a test methodology, evaluate the lines with the widest possible range of manufacturing dates and service from the five aircraft types, and conduct repeat qualification tests and degradation investigations.

The specific objectives for this program were to

1. Develop a test methodology (functional and chemical test apparatus and experimental approach).

2. Determine the reproducibility of performance among line types, manufacturing methods, and from lot to lot (manufacturing batch).

3. Determine the effects of age.

4. Determine the effects of service.

5. Determine the effects of service life followed by a repeat thermal qualification test to gain confidence for service extension.

6. Determine degradation mechanisms and limits by conducting high-temperature heat exposures.

TEST ITEMS

This section provides a generalized physical and functional description of rigid explosive transfer lines, the characteristics of the explosives used, and the specific lines tested in this program.

General Description of Rigid Transfer Lines

Rigid explosive transfer lines, shown in figure 1, are completely sealed assemblies within stainless steel. The mild detonating cord (MDC) contains a 2.5-grains-per-foot explosive core in a metal sheath. The MDC is inserted and crimped into the inner steel ferrule, which is then inserted into the stainless steel tube. The HNS-I conical charge is pressed into place in the ferrule at 32 000 psi. The booster tip output charge is loaded under the same conditions into a 0.004-in-wall-thickness steel cup, which is welded on the inner ferrule/steel tube combination to achieve the complete hermetic seal. An outer ferrule is then crimped onto the tube to provide a shoulder against which a full-rotating, threaded nut (not shown) can bear for installation into a threaded receiving port. The rubber seal seats within the receiving port to prevent contamination of explosive tip interfaces. O-rings are installed on the face of the ferrule nut and at the base of the ferrule nut threads to act as secondary seals. Both ends of the line are identical.

Explosive transfer lines are initiated by a high-pressure, explosive input pulse with well-defined thresholds (ref. 2) to the booster tip. A stable explosive shock stimulus of approximately 3 million psi propagates from the booster tip, into the ferrule charge, and into and through the mild detonating cord at a velocity in the range of 21 000 ft/sec. The explosive stimulus initiates the booster tip on the opposite end, generating an explosive pressure wave and high-velocity cup fragments. This energy can be used to accomplish work, or with the cup fragments, to transfer the explosive stimulus to other transfer lines or devices (ref. 2). The steel tubes and the end fittings, assembled into the escape system components, contain all explosive products.

Explosive Materials

The explosives used in rigid explosive transfer lines are hexanitrostilbene (HNS) and dipicramide (DIPAM). Both explosives are very insensitive to electrostatic discharge, impact, and heat. These transfer lines cannot be initiated by lightning or weapon projectiles. They will melt and burn, but will not build to detonation in a fire. However, both explosives are sensitive to photolysis (i.e., slow discoloration and degradation occurs in the presence of light). Dipicramide (DIPAM) is synthesized in an Ullman reaction from picryl chloride and nitrobenzene with copper under Navy specification WS 4660 C (ref. 3). Hexanitrostilbene (HNS) is synthesized from trinitrotoluene (TNT) and sodium hypochlorite (NaOCl), according to Navy specification WS 5003 J (ref. 4). Hexanitrobibenzyl (HNBiB) is the major impurity derived in the HNS process and is also subject to photolysis. The quantity by weight of HNBiB in HNS-I was approximately 2 percent for the AH-1, F-111, and F-14, and 6 percent for the B-1. The quantity by weight of HNBiB in HNS-II ranged from 0 to 2.1 percent. The chemical structures and melting points of these explosives are shown in figure 2. HNS-I is the initial product derived in the synthesis, yielding small particle size platelets (under 5 μm with a minimum surface area of 30 000 cm^2/cm^3). HNS-II is recrystallized from HNS-I in an organic solvent. HNS-II has larger particle sizes (approximately 50 μm with a maximum surface area of 10 000 cm^2/cm^3). HNS-I is used in booster tips because of its sensitivity to small initiation inputs (pressure impulse and fragment impacts). HNS-II is used in transfer lines because of its mechanical "flow" properties during the manufacturing process.

Types of Rigid Explosive Transfer Lines Tested

The specific lines tested in this program are described in table I, and details on manufacturing lots are given in the appendix. The listed service life is the rated value when the lines were removed. The actual ages and manufacturing dates of each group of lines are detailed in subsequent tables. The test groups used several different lots, or manufacturing batches, containing explosive materials synthesized in one processing cycle. These lines represent the three most common explosive-core and sheath combinations used in this country. Also represented are three different manufacturers and manufacturing methods. The "swage/hammer, with annealing" process starts with a work-hardened tube into which the explosive is press-loaded. The tube is moved through segmented dies, which rapidly hammer against the tube to reduce its cross section. The die diameters are reduced during multiple passes until the desired 2.5-grains-per-foot (0.05 g/m) explosive core load and external dimensions are achieved. Three 425°F, 1-hr heat cycles are allowed to relieve the work hardening of the tube during the process. The "swage/hammer, no annealing" process begins with a fully annealed tube, uses the above-described segmented dies, and does not require annealing during the process. In the "pultrusion" process, the tube is pulled through fixed dies that are reduced in diameter between passes. The strength of the silver sheath is appreciably greater than that of the aluminum sheath. Consequently, the loading density of the explosive in the silver sheath is higher, due to improved containment.

TEST APPARATUS/TECHNIQUES

The apparatus and techniques used to evaluate the rigid explosive transfer lines fall into three categories: functional, chemical/photographic, and nondestructive. The first two tests are destructive; that is, the lines are explosively initiated or dissected. Functional testing consisted of velocity and energy measurements. Chemical/photographic testing consisted of high-pressure liquid chromatography, color macrophotography, and scanning electron microscopy. The nondestructive tests were helium leak checks of end-fitting seals and X-ray inspections.

Functional Tests

Velocity measurements.- A schematic diagram of the velocity test fixture is shown in figure 3 with a list of the data types recorded. The line detonation transfer velocity V_1 was measured by recording the time interval required for the explosive stimulus to travel a known distance. A wire insulated by transparent adhesive tape was placed over a notch in the mild detonating cord (MDC) and connected to the first switch (SW 1) position in the electrical circuit in figure 4. The arrival of the explosive front short-circuits the wire at SW 1 to ground and creates an electrical pulse (discharge of the capacitor) at GATE 1 to start a time interval counter. The arrival of the explosive front at the output tip short-circuits two parallel, electrically isolated, aluminum foils (one foil attached to each side of the SW 2 location) to create a second pulse, which stops the time interval counter. The velocity of explosive propagation was calculated by dividing the measured time interval into the known distance. The explosive cord length was measured from X-rays to include cord bending within the steel tube. SW 2 also was used to start two more time interval counters to measure the axial and side booster tip fragment velocities with stop switches at SW 3 and SW 4 (parallel foil switches), respectively. The fragments impact against clear acrylic to record the distribution patterns. The acrylic tube for pattern 1 is 2.5 in. in internal diameter with a 0.5-in. wall thickness. The acrylic witness for pattern 2 is 1 × 1 × 0.5 in. These time intervals were measured with a Hewlett-Packard model 5300A measuring system mainframe and a Model 5302A universal counter with an accuracy of ± 0.1 μsec.

Energy measurement.- The energy output test fixture (ref. 5) is shown in figure 5. The transfer line end fitting is installed in the adapter, and the assembly is then installed in the initiator firing block. The free volume around the tip is filled with silicone grease to eliminate energy losses. The energy output from the booster tip is directed against the 0.50-in-diameter piston, which is in turn driven against precalibrated (approximately 700-lb strength) aluminum honeycomb cubes. The total energy is calculated by multiplying the crush distance of the honeycomb by the honeycomb strength to obtain inch-pounds. The adapter and piston cap are replaced every three shots to avoid explosive-induced deformation, which could compromise the data. A velocity of explosive propagation measurement is also made, using wire switches on the explosive transfer line outside of the test fixture.

Chemical/Photographic Tests

High-performance liquid chromatography (HPLC).- HPLC is based on physical-adsorption principles for the separation, identification, and quantification of components in a solution. (See ref. 6.) In general, HPLC involves the movement of a liquid mobile phase over a stationary solid phase under high pressures with controlled flow rates. The mainstream solvent used in this application is a 50:50 (by volume) mixture of methanol and distilled water, which is pumped into the system at pressures of approximately 2000 psi. The test sample is carefully weighed and dissolved in a measured volume of dimethylsulfoxide (DMSO). The resulting solution is quantitatively introduced into the mainstream solution. This solution is then forced radially through a packed octadecylsilane aggregate cylinder, which effects dissociation by molecular size and adhesive forces. The solution (with segregated materials) passes through a light detector, which produces voltage outputs dependent on light transmissibility. A typical plot, or time record, of the detector signal for the explosive materials used in this study is shown in figure 6. These pulses were created by high-purity standards, which provide a calibration of the system.

The equipment used for HPLC was a Waters flow system, model ALC 202, with the following components:

(a) Solvent delivery system, model 6000

(b) Radial compression separation system consisting of an RCM-100 Radial Compression Module, which applies radial pressure to the Radial-PAK Cartridge

(c) Radial-PAK Cartridge containing reverse-phase octadecylsilane (C-18) packing

(d) High-pressure loop injector, model U6K

(e) Ultraviolet detector, 254 nm, model 440

(f) Ultraviolet data module, model 730

Color macrophotography.- Photographs with a magnification of approximately 10 were made of cross sections in booster tips and explosive cords to provide a qualitative assessment of color changes. A Polaroid camera was used with a Wild Microscope (M-75, type 352873) lens. The film used was Kodak Vericolor II, type L (4 × 5).

Scanning electron microscopy (SEM).- Photographs with a magnification of 5000 were obtained with an Amray model 1000A scanning electron microscope to provide a qualitative assessment of physical structural changes. The principle of an SEM is to scan the specimen surface (within an evacuated volume) with a finely focused (6 nm) beam of electrons. The electrons interact with the specimen and create secondary emissions, such as light and X-rays. These emissions are collected and processed to form a point-after-point and line-after-line image on a cathode-ray-tube (7-in-diagonal, 2500-line-resolution) monitor, which is then photographed with a Polaroid camera. The specimens were vacuum-coated with gold to conduct the scanning electrons to ground.

Nondestructive Tests

Helium leak detection.- A Vacuum-Electronics model MS-9AB leak detector was used to evaluate the integrity of end-fitting seals. This detector was a mass spectrometer, tuned to helium. That is, the helium that leaks past the test seal is ionized, and electromagnetic fields control and position only those ions for detection to correlate with the leak rate. This detector has a sensitivity range of 1×10^{-5} to 1×10^{-9} cc/sec.

X-ray photography.- The transfer lines were inspected internally to determine if irregularities existed and to allow component measurements. The instrument used was an Automation Industries, Sperry Products Division, SPX 160 kV, model 800 X-ray source. The settings were 100 kV-A for 16 mA-min, at a focal distance of 68 in. The film was Kodak M-8 Lead Pack (14 × 17).

PROCEDURE

The program was conducted in two phases: establishing the test methodology, and conducting the experiments on rigid explosive transfer lines.

Test Methodology

The test methods (test apparatus and procedures) were established in four areas: functional tests, chemical/photographic tests, end-fitting leak tests, and X-ray inspection.

Functional tests.- The test hardware, described in the "Test Apparatus/ Techniques" section, and supporting procedures were developed using available transfer lines. To obtain a significant statistical sample, a minimum of 10 data points were obtained for each performance parameter for all test groups except the degradation investigation. The number of test lines for each group is given in the tables to follow.

Chemical/photographic tests.- The procedure used to obtain the chemical/photographic data was to dissect the explosive transfer line, take color macrophotographs, take scanning electron microphotographs (SEM's), and then perform the high-performance liquid chromatography (HPLC) analyses (see "Test Apparatus/Techniques" section).

The booster tip was dissected with a tube cutter at the ferrule-charge-to-booster-charge plane (fig. 7(a)). The cup was cut and then broken open to minimize any physical disturbance to the exposed explosive. The explosive cord was cut in the same manner at a distance of 2.5 cm from each end and at the midpoint if the cord was greater than 25 cm in length (fig. 7(b)). The explosive cord was also filed longitudinally with a jeweler's flat file (second cut) to expose the core. The exposed explosives were then photographed in color, and a small sample was taken for scanning electron microphotography.

The sampling of explosive material for the HPLC analysis used different approaches for the booster tip and transfer line. For the booster tip analyses, all the HNS was extracted from the cup, and the material was mechanically blended. A quantitative sample weight was removed and dissolved in DMSO solvent. For the transfer line analyses, a 1 to 2 mm cross-sectional length was cut from the explosive cord. DMSO solvent was added to the transfer line sample, and this solution was then placed in an ultrasonic bath for approximately 30 min to completely dissolve the explosive from the metal sheath. The quantity of explosive was determined by the weight difference between the original and empty cord length. Two or more transfer lines were tested from each group with a minimum of three HPLC analyses determined on each sample. More lines and samples were tested whenever changes were observed. The accuracy of analysis was ±3 percent for HNS-I and ±5 percent for HNS-II and DIPAM. The process for removing the HNS-II and DIPAM from the cord caused this slight decrease in accuracy.

End-fitting leak tests.- Helium leak tests were conducted to determine seal integrity on 50 end fittings of transfer lines removed after rated service. The lines were installed in a standard port, adapted to the leak detector. The leak detector was evacuated to less than 1 mm of Hg, and the detection system was activated. A bag was placed around the transfer line and completely purged with helium to assure that only helium was present at the seal interface. The acceptance criterion was a leak rate no greater than 1×10^{-5} cc/sec at 1 atm differential pressure, which is the standard procurement specification.

X-ray inspection.- The lines were X-rayed from end to end in a single plane. The inspection objective was to identify any nonuniformities or displaced components. This inspection was conducted on receipt of the transfer lines and after each environmental test, prior to firing or dissecting. The X-rays also provided a method of accurately determining the lengths of the explosive cord.

Experimental Test Programs

The experimental test programs for the rigid explosive transfer lines removed from the five aircraft types are detailed in tables II through VI. This section describes the objectives and laboratory procedures for the different phases of the program - obtaining the test hardware, nondestructive testing, establishing a performance standard, demonstrating shelf life, demonstrating service life, repeating thermal qualification tests, and conducting a degradation investigation.

Test hardware.- The objectives were to obtain all the types of transfer lines used in this country and to obtain groups of transfer lines with the widest possible range of age and service (tables II through VI). The available lines were divided into groups for testing as described below; exact duplication of all tests among all aircraft types was not possible.

For each line, the aircraft, service, manufacturer, manufacturing lot, manufacturing date, part number, and serial number were recorded. These records were maintained throughout the test program, and the final disposition of all lines was documented.

Nondestructive tests.- The objective was to determine the as-received status of all lines by visual and X-ray inspection. These tests were also conducted after environmental exposures. Furthermore, a random sample of 50 end fittings from the oldest available lines with full service were leak tested to determine the effects of age and service.

Performance standard.- The objective of this test group was to establish functional performance and chemical composition standards, against which all subsequent test groups were compared. The most recently manufactured lines with the least service were used. Ideally, new lines with no service would provide the best performance and analysis reference. However, only the AH-1S aircraft had new lines available. Twenty lines were tested functionally, and two were chemically analyzed.

Shelf life demonstration.- The objective of this group was to determine the effects of age without any service. The only available components with significant age (7 to 8 years) and no service were the spares for the B-1 aircraft system qualification. Twenty lines were tested functionally, and two were chemically analyzed.

Service life demonstration.- The objective of this group was to determine the effects of rated, installed service time for each aircraft. For all aircraft except the AH-1G, the oldest age-with-service group was used for this evaluation. Since the AH-1G had only one age group, the service life demonstration was omitted. Twenty lines were tested functionally, and two were chemically analyzed.

Repeat thermal qualification.- The objective of this test group was to increase confidence in extending the service life of rigid explosive transfer lines by subjecting transfer lines with full service to a repeat of the original thermal qualification tests (see tables II through VI and fig. 8). Mechanical environmental tests were not conducted, since past experience has shown that transfer lines are not affected by qualification-level mechanical inputs. All lines were inspected; 40 lines were functionally tested, and 4 were chemically analyzed.

Degradation investigation.- The objective of this test group was to determine what chemical and physical changes take place as transfer lines degrade, and how much degradation causes functional failure. The only known method for inducing degradation was through exposure to elevated temperatures, since no age effect had been proven. Groups of 14 to 17 transfer lines were subjected to 50-hr exposures to 375°F, 400°F, 425°F, and 450°F (one temperature level per group). The lines were inspected, 12 to 15 were functionally tested, and 2 were chemically analyzed. When a high percentage of functional failures occurred, subsequent groups were tested at lower temperature/time levels to assess more accurately degradation mechanisms. To explore wider degradation limits, three lines from F-111 aircraft were exposed to 500°F for 50 hr, and chemical analyses were performed after the exposures.

RESULTS

The experimental results for the more than 800 transfer lines tested in this program are divided into four areas: seal tests of end fittings, functional performance and chemical analyses, degradation investigations, and photographic analyses.

Seal Tests of End Fittings

The leak tests for the 50-sample groups removed after rated service from the five aircraft are summarized in table VII. The ferrule nut O-rings on the face of the nut and at the base of the threads were often badly deteriorated or missing. The actual seal was established by the conical seal at the base of the booster tip. Many of these seals had been damaged in the installation and removal cycle. Although some damage was assessed in a substantial number of seals, only 17 of 250 (7 percent) indicated leakage rates greater than 1×10^{-5} cc/sec.

Functional Performance and Chemical Analyses

The functional performance and chemical analysis results are detailed in tables VIII through XII. Each table heading describes the aircraft type and the years of transfer line service. The test group column identifies the type of test conducted (see "Experimental Test Programs"). The second column is the time range during which the lines in the respective groups were manufactured, and the third column is the date when the test firings were conducted. The number of test firings is also shown. The velocity and energy data are averaged for each group, with a standard deviation as a percentage of the average shown in parentheses. A high degree of functional and chemical uniformity was observed in the performance standards for all line types. The appendix shows the line manufacturers and the large number of lots tested. In the groups where functional failures occurred, the failures were not included in the average or standard deviation. For the chemical analyses, the repetitive runs to determine the total explosive quantities (i.e., HNS/HNBiB or DIPAM) from the multiple samples from the lines were averaged. The variations in the performance standard group data, expressed as the percentage of the standard deviation to the average, were: line velocity - 4 percent or less, axial fragment velocity - 11 percent or less, side fragment velocity - 4 percent or less, and energy output - 12 percent or less. No significant change in velocities, energy output, or chemical composition was observed in the age, service life, or repeat thermal qualification groups, as compared with the respective performance standards. Transfer line ages ranged from about 1 year to 10 years. Service ranged from 3 years to 7 years.

Degradation Investigation

All aircraft line types performed with little change (functional or chemical) following the 375°F, 50-hr exposure. However, explosive propagation failures occurred following the 400°F, 50-hr exposure for the HNS in silver detonating cords from the AH-1G (4 of 12), AH-1S (2 of 13), and F-14 (1 of 14). Chemical analysis of the transfer lines in which failures occurred showed 88 percent as the highest amount of explosive remaining in any failed line. Following the 425°F, 50-hr exposure, all lines failed in the AH-1G group, and 9 of 14 lines failed in the F-14 group. For HNS-II in aluminum lines (B-1 aircraft), an appreciable amount of chemical degradation occurred following a 425°F/50-hr heat cycle; all functional tests were successful. The HNS-II degradation was less in the aluminum sheathing with lower explosive loading density than that observed in the silver sheathing. Failures also occurred in F-111 booster tips at 450°F for 50 hr with chemical analyses showing as much as 80-percent explosive remaining.

The effect of heat on the chemical composition of four aircraft transfer lines and booster tips is shown in table XIII. Only one lot was used for each aircraft type. No appreciable change was observed in the repeat of the thermal qualification tests, but the explosive quantities decreased at the higher temperature exposures. The quantity of hexanitrobibenzyl (HNBiB, melting point 424°F) decreased prior to a decrease in hexanitrostilbene (HNS, melting point 601°F or 604°F). The dipicramide (DIPAM) exhibited no change after any of the thermal exposures including 450°F for 50 hr. The DIPAM was reduced to 5.4 percent at 500°F for 50 hr, and these lines would obviously be nonfunctional.

The above data are further substantiated by external physical changes in the booster tip, as shown in table XIV. Only one lot was used for each aircraft type. The end faces of the booster tips exhibited pronounced swelling, caused by explosive outgassing, as heat loads were applied. Two different aircraft test groups, F-111 and AH-1G, having 3.4 and 1.7 percent by weight of HNBiB, respectively, were monitored. The F-111 tips swelled twice as much as the AH-1G tips, and 40 percent of the F-111 tips burst when exposed to 450°F for 50 hr.

Photographic Analyses

Color macrophotographs and scanning electron micrographs provided qualitative corroboration of the functional performance, chemical composition, and physical data reported in the above sections.

Figures 9(a) and 10(a) show the only "new" explosive samples. The AH-1S transfer lines were the only samples that were recently manufactured and had no flight service. However, no appreciable color or SEM differences were observed in the AH-1S or AH-1G service or repeat thermal qualification samples, as shown in figures 9 through 14.

As heat-induced degradation occurred in the AH-1G HNS explosives, both the color and physical texture of the explosives changed, as shown in figures 11 through 14. The booster tip explosive gradually darkened from the outer circumference inward (fig. 15). The SEM's (figs. 12 and 14) indicate a gradual roughening of the particles as degradation increases, to a perforated "Swiss cheese" texture, where the explosive becomes nonfunctional. Figures 15 and 16 provide further examples of degradation. Careful removal and analysis of the darkened outer explosive in figure 15 revealed considerably more degradation than in the central material. In figure 16, the darkest colors and color gradation correspond with highest density at the major diameter, and the lightest colors correspond with the lowest density at the smallest diameter. These density variations are induced by pressing the explosive into a conical cavity.

However, heat is not the only cause of color changes, as shown in the F-14 booster tips in figure 17. Both tips had 3 years of service, but the darkened tip is 3 years younger and more pure (less HNBiB) than the bright-colored tip. Evidently, the darkened tip material had been exposed to light prior to final assembly, and superficial photolysis had been initiated.

Figures 18 through 20 highlight the test extremes for the F-14, B-1, and F-111 transfer lines, respectively. No changes were observed with service and age. For the F-14 lines, the 425°F, 50-hr sample was nonfunctional. Although some change was detected for the B-1 lines after exposure to 425°F for 50 hr, all lines remained functional. No changes in color or physical appearance were detected for the F-111 DIPAM lines after exposure to 450°F for 50 hr (fig. 20). Total decomposition occurred in a 500°F, 50-hr exposure.

CONCLUSIONS

Extending the service life of rigid explosive transfer lines, used to initiate emergency aircraft crew escape systems, provides the potential of considerable savings for military and NASA aircraft. The rated service life of rigid explosive transfer lines has been established on a conservative basis because of uncertainty concerning the stability of explosives and limited technical information on functionality following age and service. The purpose of the effort described in this paper was to determine quantitatively the effects of service, age, and degradation on rigid explosive transfer lines to allow responsible, conservative, service life determinations. The technical approach was to evaluate transfer lines with no service and lines removed after rated service from five military aircraft: the Army AH-1G and AH-1S, the Air Force B-1 and F-111, and the Navy F-14. These lines represent all three line types in use in this country, that is, recrystallized hexanitrostilbene (HNS-II) in a silver sheath, HNS-II in an aluminum sheath, and dipicramide (DIPAM) in a silver sheath. The lines were evaluated with no service, after rated service, after service with age, and after service followed by a repeat of the initial thermal qualification tests. A degradation investigation was also conducted to determine limits and mechanisms through which degradation occurs.

The results of the test program, in which more than 800 transfer lines were evaluated, indicated that all program objectives were met.

1. The test methodology was sufficiently accurate to detect changes in physical condition, functional performance, and chemical composition.

2. A high degree of uniformity, as measured by the above test methodology, exists among line types, manufacturing methods, and from lot to lot.

3. No detectable change occurred with age up to 10 years.

4. No detectable change occurred with service up to 7 years.

5. No detectable change occurred with rated service and a repeat thermal qualification test.

6. The sealing ability of transfer line end fittings was excellent following age and service. Sealing was achieved by the rubber seal on the tip with no contribution from ferrule nut O-rings.

7. Degradation occurred, but at temperatures substantially in excess of service requirements. The investigation revealed that HNS with HNBiB was the first material to degrade. The approximate degradation limits for HNS/HNBiB are above 88 percent by weight in the line and 80 percent in the booster tip. That is, failures began at thermally induced degradation of 88 percent by weight in the transfer lines and 80 percent in the booster tips. Degradation was accelerated by increased explosive loading density and by higher quantities of HNBiB. Aluminum-sheathed detonating cord with a lower HNS density was more thermally stable than silver-sheathed cord. Serious degradation was detectable externally by tip swelling.

8. The silver-sheathed DIPAM detonating cord was more thermally stable than cords using silver- or aluminum-sheathed HNS. The DIPAM cords withstood 450°F for 50 hr with no change. The HNS-II in silver cords withstood 375°F for 50 hr, and the HNS-II in aluminum cords withstood 425°F for 50 hr with appreciable but acceptable change.

Absolute, quantitative test methodology now exists to evaluate transfer lines functionally and chemically. This test program demonstrated that rigid explosive transfer lines, produced by several manufacturing methods, are high-quality, highly stable devices. Clearly, the lines tested in this program were removed from service too soon. Extending service life would not only result in considerable cost savings, but would also increase system reliability by avoiding potential damage caused by system disassembly and removal.

RECOMMENDATIONS

1. A service life extension of rigid explosive transfer lines should be considered.

2. The suggested approach for service life extension on established systems is to either

a. Compare requirements of the subject system with the state-of-the-art service life demonstrations of other systems and utilize the appropriate technology base, or

b. Leaving the original rigid explosive transfer lines installed in the system, conduct an evaluation of a sample of the line population at the completion of the specified service life and annually thereafter. This sample (25 units minimum) should be made up of the oldest lines with the most severe high-temperature service. The evaluation should consist of a physical inspection, functional performance tests, and chemical analyses for comparison with the standards developed in this program. The results of these comparisons would permit informed service extension decisions.

3. The suggested approach for new systems is to incorporate the test methodology developed in this program into the initial subsystem specifications. A performance standard would be established on the original manufacturing lot(s) of lines. Upon completion of the recognized service life, the procedure in item 2b above would be instituted.

4. The above approach should be applied to the evaluation of other components that utilize similar explosives and designs.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
March 17, 1983

APPENDIX

MANUFACTURING LOTS OF TRANSFER LINE TEST GROUPS

Lot numbers and manufacture dates for the transfer lines used in the test groups for the five aircraft are listed in tables AI through AV.

TABLE AI.- AH-1G AIRCRAFT

[Teledyne McCormick-Selph transfer lines]

Test group	Lot	Manufacture date
Performance standard	7180-13	9-72
	7180-12	8-72
	7180-8	7-72
	7180-9	7-72
	7180-6	6-72
	7180-3	5-72
	7452-3	10-73
	7180-1	3-72
	7180-2	4-72
	7180-7	6-72
Degradation investigation	7180-7	6-72
	7180-9	7-72
	7180-11	8-72
	7180-12	8-72
	7180-13	9-72
	7452-2	8-73
	7967-1	2-77
	7452-3	10-73
	7180-3	5-72
Repeat thermal qualification	7180-6	6-72
	7180-7	6-72
	7180-8	7-72
	7180-9	7-72
	7180-11	8-72
	7180-12	8-72
	7452-2	8-73
	7452-4	12-73
	7180-1	3-72
	7180-13	9-72
	7180-3	5-72
	7180-4	5-72
	7180-2	4-72

TABLE AII.- AH-1S AIRCRAFT

[Space Ordnance Systems transfer lines]

Test group	Lot	Manufacture date
Performance standard	TAE-11	12-79
	SNE-5	7-77
	SNE-15	5-78
Degradation investigation	SNE-15	5-78
	SNE-5	7-77
	SNE-1	6-77
	SNE-3	7-77
	TAE-11	12-79
	SNE-4	7-77
Service life demonstration	SLC	4-77
	SLC-3	5-77
	SNE-14	2-78
Repeat thermal qualification	SLC	4-77
	Unknown	8-77
	Unknown	6-77
	SNE-4	7-77
	SLC-5	6-77
	SNE-6	8-77
	SNE-11	9-77
	SNE-11	2-77
	SNE-10	9-77
	SNE-9	9-77
	SNE-14	2-78

APPENDIX

TABLE AIII.- F-14 AIRCRAFT

[Explosive Technology transfer lines]

Test group	Lot	Manufacture date
Performance standard	ETI-2-205	12-74
	ETI-2-208	1-75
	ETI-2-211	1-75
	ETI-2-212	1-75
	3-ETI-0275	2-75
	4-ETI-0275	2-75
	5-ETI-0275	2-75
Degradation investigation	5-ETI-0275	2-75
	3-ETI-0275	2-75
	1-ETI-0275	2-75
	2-ETI-0275	2-75
	ETI-2-213	2-75
	4-ETI-0275	2-75
	6-ETI-0375	3-75
	8-ETI-0325	3-75
	9-ETI-0375	3-75
	10-ETI-0375	3-75
	11-ETI-0375	3-75
	7-ETI-0375	3-75
	12-ETI-0375	3-75
	13-ETI-0375	3-75
	14-ETI-0375	3-75
	40-ETI-0575	5-75
	58-ETI-0775	7-75
Service life demonstration	36	2-71
	Unknown	3-71
	50	4-71
	48	4-71
	3002-57	2-72
	3002-61	3-72
	3002-65	4-72
	3002-68	5-72
	3002-67	5-72
	3002-91	6-72
	3002-78	7-72
	3002-79	7-72
Repeat thermal qualification	3002-79	7-72
	3002-78	7-72
	3002-77	7-72
	3002-74	7-72
	3002-76	7-72
	3002-75	7-72
	3002-80	8-72
	3002-81	8-72
	3002-82	8-72
	3002-83	9-72
	3002-85	9-72
	3002-86	9-72
	3002-87	9-72
	3002-88	9-72
	3002-89	9-72
	3002-92	10-72
	ETI-2-150	10-73

TABLE AIV.- B-1 AIRCRAFT

[Teledyne McCormick-Selph transfer lines]

Test group	Lot	Manufacture date
Performance standard	7886-21	3-77
Degradation investigation	7886-21	3-77
	7886-26	3-77
Service life demonstration	7060-Unknown	4-73
	7060-Unknown	5-73
	7060-Unknown	6-73
	7060-Unknown	8-73
	7060-Unknown	11-74
	7060-212	4-73
	7060-226	5-73
	7060-213	4-73
	7060-233	6-73
	7060-269	7-73
	7060-230	6-73
Shelf life demonstration (no service)	Unknown	6-73
	7060-269	7-73
	Unknown	11-72
	Unknown	10-72
Repeat thermal qualification	7060-217	4-73
	7060-205	3-73
	7060-214	7-73
	7060-230	6-73
	7060-253A	6-73
	7060-274	7-73
	7060-275	7-73
	7060-270	7-73
	7060-273	7-73
	7060-214	4-73
	7060-216	4-73
	7060-Unknown	4-73
	7060-282	8-73
	7060-212	4-73
	7060-229	5-73
	7060-260	6-73
	7060-226	5-73
	7060-232	6-73

TABLE AV.- F-111 AIRCRAFT

[Teledyne McCormick-Selph transfer lines]

Test group	Lot	Manufacture date
Performance standard	MSV8555-5	1-75
Degradation investigation	MSV8555-3	10-74
	MSV8555-4	11-74
	MSV8555-5	1-75
	MSV8555-6	2-75
Service life demonstration	MSV8553-1	4-72
	MSV8553-2	4-72
	MSV8553-4	4-72
	MSV8553-5	5-72
	MSV8553-6	5-72
	MSV8553-8	5-72
	MSV8553-9	6-72
	MSV8553-10	6-72
Repeat thermal qualification	MSV8553-1	4-72
	MSV8553-4	4-72
	MSV8553-5	5-72
	MSV8553-6	5-72
	MSV8553-8	5-72
	MSV8553-9	6-72
	MSV8553-10	6-72
	MSV8553-3	4-72
	MSV8551-6	11-71
	MSV8553-11	6-72
	MSV8551-12	11-71
	MSV8551-43	1-72

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TABLE I.- RIGID EXPLOSIVE TRANSFER LINES TESTED

Aircraft	Explosive core	MDC sheath	Manufacturing process for MDC	Rated service, years
AH-1G	HNS-II	Silver	Swage/hammer, with annealing	7
AH-1S	HNS-II	Silver	Pultrusion	5
F-14	HNS-II	Silver	Swage/hammer, no annealing	3
B-1	HNS-II	Aluminum	Swage/hammer, with annealing	3
F-111	DIPAM	Silver	Swage/hammer, with annealing	4

TABLE II.- TEST PROGRAM FOR RIGID EXPLOSIVE TRANSFER LINES ON AH-1G AIRCRAFT

1. Transfer lines were obtained. The lines had an average of 7 years of service and were manufactured in 1972.

2. Visual and X-ray inspections were conducted on all lines.

3. Helium leak tests were performed on 50 end fittings.

4. Performance standards were established.

   a. Functional performance tests were conducted on 20 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

5. Thermal qualification tests were repeated.

   a. Twenty-two lines were subjected to -110°F for 72 hr.

   b. Twenty-two lines were subjected to +200°F for 72 hr.

   c. Visual and X-ray inspections were conducted on all lines.

   d. Functional performance tests (20 lines) and chemical/photographic tests (2 lines) were conducted on each exposure group.

6. A degradation investigation was conducted.

   a. Forty-two lines were subjected to thermal exposures. Fourteen lines were subjected to 375°F for 50 hr, 14 lines were subjected to 400°F for 50 hr, and 14 lines were subjected to 425°F for 50 hr.

   b. Visual and X-ray inspections were conducted on all lines.

   c. Functional performance tests (12 lines) and chemical/photographic tests (2 lines) were conducted on each exposure group.

TABLE III.- TEST PROGRAM FOR RIGID EXPLOSIVE TRANSFER LINES ON AH-1S AIRCRAFT

1. Transfer lines were obtained.

   a. Group A consisted of new lines with no service. These lines were manufactured in 1977 to 1979.

   b. Group B consisted of lines removed from aircraft after an average of 4.7 years of service. These lines were manufactured in 1977 and 1978.

2. Visual and X-ray inspections were conducted on all lines.

3. Helium leak tests were performed on 50 end fittings from group B lines.

4. Performance standards were established using group A lines.

   a. Functional performance tests were conducted on 21 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

5. A service life demonstration was conducted using group B lines.

   a. Functional performance tests were conducted on 20 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

6. Thermal qualification tests were repeated on group B lines.

   a. Twenty-two lines were subjected to -110°F for 72 hr.

   b. Twenty-two lines were subjected to +200°F for 72 hr.

   c. Visual and X-ray inspections were conducted on all lines.

   d. Functional performance tests (20 lines) and chemical/photographic tests (2 lines) were conducted on each exposure group.

7. A degradation investigation was conducted on group A lines.

   a. Twenty-eight lines were subjected to thermal exposures. Fourteen lines were exposed to 375°F for 50 hr, and 14 lines were exposed to 400°F for 50 hr.

   b. Visual and X-ray inspections were performed on all lines.

   c. Functional performance tests (12 lines) and chemical/photographic tests (2 lines) were conducted on each exposure group.

TABLE IV.- TEST PROGRAM FOR RIGID EXPLOSIVE TRANSFER LINES ON F-14 AIRCRAFT

1. Transfer lines were obtained.

   a. Group A consisted of lines removed from Aircraft 1 after 3 years of service. These lines were manufactured in 1971 and 1972.

   b. Group B consisted of lines removed from aircraft after 3 years of service. These lines were manufactured in 1974 and 1975.

2. Visual and X-ray inspections were conducted on all lines.

3. Helium leak tests were performed on 50 end fittings from group A lines.

4. Performance standards were established using group B lines.

   a. Functional performance tests were conducted on 20 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

5. A service life demonstration was conducted using group A lines.

   a. Functional performance tests were conducted on 20 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

6. Thermal qualification tests were repeated on group A lines.

   a. Forty-four lines were subjected to 100 thermal cycles (see fig. 8(a)).

   b. Visual and X-ray inspections were conducted on all lines.

   c. Functional performance tests were conducted on 40 lines, and chemical/photographic tests were conducted on 4 lines.

7. A degradation investigation was conducted on group B lines.

   a. Forty-eight lines were subjected to thermal exposures. Sixteen lines were exposed to 375°F for 50 hr, 16 lines were exposed to 400°F for 50 hr, and 16 lines were exposed to 425°F for 50 hr.

   b. Visual and X-ray inspections were performed on all lines.

   c. Functional performance tests (14 lines) and chemical/photographic tests (2 lines) were conducted on each exposure group.

TABLE V.- TEST PROGRAM FOR RIGID EXPLOSIVE TRANSFER LINES ON B-1 AIRCRAFT

1. Transfer lines were obtained.

   a. Group A consisted of lines removed from Aircraft 1 after 3 years of service. These lines were manufactured in 1972 to 1974.

   b. Group B consisted of lines removed from storage with no service. These lines were manufactured in 1972 and 1973.

   c. Group C consisted of lines removed from aircraft after 3 years of service. These lines were manufactured in 1977.

2. Visual and X-ray inspections were conducted on all lines.

3. Helium leak tests were performed on 50 end fittings from group A lines.

4. Performance standards were established using group C lines.

   a. Functional performance tests were conducted on 22 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

5. A shelf life demonstration was conducted using group B lines.

   a. Functional performance tests were conducted on 28 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

6. A service life demonstration was conducted using group A lines.

   a. Functional performance tests were conducted on 21 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

7. Thermal qualification tests were repeated on group A lines.

   a. Forty-four lines were subjected to 100 thermal cycles (see fig. 8(b)).

   b. Visual and X-ray inspections were conducted on all lines.

   c. Functional performance tests were conducted on 40 lines, and chemical/photographic tests were conducted on 4 lines.

8. A degradation investigation was conducted using group C lines.

   a. Forty-eight lines were subjected to thermal exposures. Sixteen lines were exposed to 375°F for 50 hr, 16 lines were exposed to 400°F for 50 hr, and 16 lines were exposed to 425°F for 50 hr.

   b. Visual and X-ray inspections were performed on all lines.

   c. Functional performance tests (14 lines) and chemical/photographic tests (2 lines) were conducted on each exposure group.

TABLE VI.- TEST PROGRAM FOR RIGID EXPLOSIVE TRANSFER LINES ON F-111 AIRCRAFT

1. Transfer lines were obtained. All lines were removed from aircraft after 4 years of service.

   a. Group A consisted of lines manufactured in 1971 and 1972.

   b. Group B consisted of lines manufactured in 1975.

2. Visual and X-ray inspections were conducted on all lines.

3. Helium leak tests were performed on 50 end fittings from group A lines.

4. Performance standards were established using group B lines.

   a. Functional performance tests were conducted on 22 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

5. A service life demonstration was conducted using group A lines.

   a. Functional performance tests were conducted on 20 lines.

   b. Chemical/photographic tests were conducted on 2 lines.

6. Thermal qualification tests were repeated on group A lines.

   a. Forty-four lines were subjected to 100 thermal cycles (see fig. 8(c)).

   b. Visual and X-ray inspections were conducted on all lines.

   c. Functional performance tests were conducted on 40 lines, and chemical/photographic tests were conducted on 4 lines.

7. A degradation investigation was conducted using group B lines.

   a. Forty-eight lines were subjected to thermal exposures. Fifteen lines were exposed to 400°F for 50 hr, 15 lines were exposed to 425°F for 50 hr, 15 lines were exposed to 450°F for 50 hr, and 3 lines were exposed to 500°F for 50 hr.

   b. Visual and X-ray inspections were conducted on all lines.

   c. Functional performance tests (13 lines) and chemical/photographic tests (2 lines) were conducted on the 400°F, 425°F, and 450°F exposure groups. For the 500°F exposure group, all 3 lines were analyzed chemically.

TABLE VII.- RESULTS OF END-FITTING SEAL TESTS

Aircraft	Manufacture date	Service life, years	No. of leaks $>1 \times 10^{-5}$ cc/sec in 50 tests
AH-1G	5/72 to 2/77	7	1
AH-1S	4/77 to 3/78	4.7	0
F-14	3/71 to 6/75	3	3
B-1	10/72 to 7/73	3	2
F-111	1/72 to 2/75	4	11

TABLE VIII.- FUNCTIONAL AND CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES ON AH-1G AIRCRAFT

[7 years service]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)					Average chemical analysis results		
			No. test firings	Velocity, ft/sec			Energy, in-lb	No. tested	Percent total explosive by weight	
				Line	Axial fragment	Side fragment			HNS-II/HNBiB in transfer line	HNS-I/HNBiB in booster tip
Performance standard	3/72	9/80	20	22 257 (1.7)	8842 (5.2)	8575 (3.7)	554 (7.6)	2	96.5	100.4
Repeat thermal qualification:	6/72 to 8/72									
-110°F for 72 hr		12/80	20	21 629 (2.8)	9338 (10.6)	9285 (6.2)	523 (13.0)	2	96.8	98.1
+200°F for 72 hr		12/80	20	21 791 (2.4)	9012 (3.4)	9014 (6.9)	497 (12.2)	2	96.0	97.6
Degradation investigation:	6/72 to 8/72									
375°F for 50 hr		10/80	12	20 494 (5.5)	8999 (8.6)	9094 (6.3)	469 (6.6)	2	97.3	96.7
400°F for 50 hr		3/81	12	[a]18 017 (5.2)	9054 (5.4)	8110 (8.5)	458 (23.3)	2	72.4	93.7
425°F for 50 hr		10/80	3	Lines failed to propagate				2	23.2	91.8

[a]Four propagation failures at line-to-tip interface.

TABLE IX.- FUNCTIONAL AND CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES ON AH-1S AIRCRAFT

[4.7 years service]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)					Average chemical analysis results		
			No. test firings	Velocity, ft/sec			Energy, in-lb	No. tested	Percent total explosive by weight	
				Line	Axial fragment	Side fragment			HNS-II/HNBiB in transfer line	HNS-I/HNBiB in booster tip
Performance standard (no service)	7/77 to 12/79	1/81	21	22 737 (0.9)	9 366 (11.4)	8183 (3.6)	511 (12.3)	2	97.0	99.8
Service life demonstration	4/77 to 2/78	6/82	20	22 726 (1.7)	10 511 (10.8)	8778 (4.9)	414 (17.9)	2	98.7	99.4
Repeat thermal qualification:	4/77 to 3/78	7/82								
-110°F for 72 hr			20	22 768 (1.3)	9 898 (14.8)	8614 (11.1)	442 (16.5)	2	99.1	99.8
+200°F for 72 hr			20	22 804 (0.9)	10 459 (7.7)	8985 (4.9)	469 (17.9)	2	96.7	100.9
Degradation investigation:	6/77 to 5/78									
375°F for 50 hr		2/81	12	22 944 (0.5)	9 415 (11.3)	8198 (2.5)	458 (23.4)	2	99.8	98.0
400°F for 50 hr		3/81	13	22 918 (0.9)	9 549 (12.5)	8249 (5.4)	[a]446 (6.0)	4	88.0	94.1

[a]Two propagation failures at mid line.

TABLE X.- FUNCTIONAL AND CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES ON F-14 AIRCRAFT

[3 years service]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)					Average chemical analysis results		
			No. test firings	Velocity, ft/sec			Energy, in-lb	No. tested	Percent total explosive by weight	
				Line	Axial fragment	Side fragment			HNS-II/HNBiB in transfer line	HNS-I/HNBiB in booster tip
Performance standard	12/74 to 2/75	10/81	20	21 176 (4.2)	9575 (10.0)	8754 (3.8)	461 (9.8)	2	100.0	99.4
Service life demonstration	2/71 to 7/72	10/81	20	22 277 (2.6)	9797 (7.6)	8174 (3.2)	490 (11.8)	2	100.0	99.9
Repeat thermal qualification	7/72 to 10/73	1/82	40	22 565 (2.9)	9597 (7.2)	8237 (5.6)	439 (15.7)	3	97.7	97.0
Degradation investigation:	2/75 to 3/75									
375°F for 50 hr		10/81	14	20 411 (2.2)	9402 (14.8)	8677 (5.5)	516 (15.1)	3	99.1	96.9
400°F for 50 hr		12/81	14	[a]20 475 (2.3)	9661 (7.9)	8789 (5.8)	369 (33.1)	3	94.6	93.4
425°F for 50 hr		11/81	14	[b]17 407 (11.2)	9126 (7.7)	8616 (6.7)	537 (12.7)	8	68.3	92.4

[a]One propagation failure at tip.
[b]Nine propagation failures at tip.

TABLE XI.- FUNCTIONAL AND CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES ON B-1 AIRCRAFT

[3 years service]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)					Average chemical analysis results		
			No. test firings	Velocity, ft/sec			Energy, in-lb	No. tested	Percent total explosive by weight	
				Line	Axial fragment	Side fragment			HNS-II/HNBiB in transfer line	HNS-I/HNBiB in booster tip
Performance standard	3/77	7/80	22	20 593 (2.9)	9367 (4.1)	8185 (4.1)	491 (12.0)	2	97.0	98.9
Shelf life demonstration (no service)	10/72 to 7/73	7/80	28	20 599 (1.5)	9517 (11.1)	8699 (4.0)	503 (7.2)	2	97.9	98.8
Service life demonstration	4/73 to 11/74	4/81	21	20 170 (1.5)	9172 (8.5)	8532 (13.8)	433 (9.0)	2	95.7	97.1
Repeat thermal qualification	3/73 to 8/73	5/81	40	20 097 (2.0)	9268 (7.3)	8883 (6.5)	419 (11.5)	2	95.9	95.0
Degradation investigation:	3/77									
375°F for 50 hr		11/80	13	20 535 (2.1)	9229 (5.2)	8842 (3.1)	518 (10.8)	2	100.0	99.3
400°F for 50 hr		5/81	14	20 141 (1.6)	9685 (5.6)	8795 (5.0)	419 (11.9)	2	93.5	94.9
425°F for 50 hr		5/81	14	20 348 (2.5)	8594 (6.2)	8084 (7.6)	448 (12.9)	2	88.4	89.5

TABLE XII.- FUNCTIONAL AND CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES ON F-111 AIRCRAFT

[4 years service]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)					Average chemical analysis results		
			No. test firings	Velocity, ft/sec			Energy, in-lb	No. tested	Percent total explosive by weight	
				Line	Axial fragment	Side fragment			DIPAM in transfer line	HNS-I/HNBiB in booster tip
Performance standard	1/75	6/80	22	23 534 (0.9)	9655 (3.3)	7650 (3.1)	537 (7.6)	2	100.0	101.8
Service life demonstration	4/72 to 6/72	12/80	20	23 604 (1.2)	8940 (4.8)	8805 (3.1)	513 (10.7)	2	99.3	101.2
Repeat thermal qualification	11/71 to 6/72	2/81	42	23 183 (2.6)	9748 (12.3)	9509 (12.6)	506 (12.6)	2	98.6	99.5
Degradation investigation:	1/75									
400°F for 50 hr		9/80	13	23 336 (1.4)	9045 (1.3)	7704 (2.5)	480 (4.8)	2	99.4	93.3
425°F for 50 hr		10/80	13	23 135 (1.3)	8628 (4.9)	7633 (2.5)	503 (14.3)	2	98.3	80.5
450°F for 50 hr		7/80	8	22 076 (3.4)	Tips burst, 12 of 30	6285 (3.5)	429 (4.0)	12	100.0	68.7
500°F for 50 hr		6/82	No test					3	5.4	21.7

TABLE XIII.- EFFECT OF HEAT ON CHEMICAL COMPOSITION

Aircraft	Explosive (sheath)	Percent explosive weight remaining (average)					
		As received	Repeat thermal qualification	375°F/50 hr	400°F/50 hr	425°F/50 hr	450°F/50 hr
Transfer lines							
AH-1G	HNS-II/HNBiB (silver)	96.5/0.6	94.8/1.0	98.4/0.2	77.0/0.2	23.2/0	No test
F-14	HNS-II/HNBiB (silver)	100/0	97.7/0	99.1/0	94.6/0	68.2/0.2	No test
B-1	HNS-II/HNBiB (aluminum)	97.5/0	94.3/1.6	100/0	93.5/0	88.4/0	No test
F-111	DIPAM (silver)	98.4	98.6	No test	99.4	98.3	100
Booster tips							
AH-1G	HNS-I/HNBiB (304 stainless steel)	96.2/3.3	94.8/2.4	95.2/2.7	91.5/2.2	90.7/1.1	No test
F-14		98.6/0.8	93.5/2.9	93.4/3.3	91.0/1.6	90.2/2.2	No test
B-1		93.4/5.5	89.0/6.0	94.4/4.8	88.9/5.1	86.7/3.3	No test
F-111		97.5/2.5	97.7/1.8	No test	91.0/2.3	79.1/1.4	74.8/0.9

TABLE XIV.- AVERAGE BOOSTER TIP SWELLING AFTER THERMAL EXPOSURE

[30 tips/data point]

Temperature/time	F-111 (3.4 percent HNBiB)		AH-1G (1.7 percent HNBiB)	
	Swelling, in.	Std. dev., in.	Swelling, in.	Std. dev., in.
375°F/50 hr	No test		0.0011	0.0013
400°F/50 hr	0.0022	0.0012	Not monitored	
425°F/50 hr	.0099	.0042	.0049	.0027
450°F/50 hr	12 of 30 burst		No test	

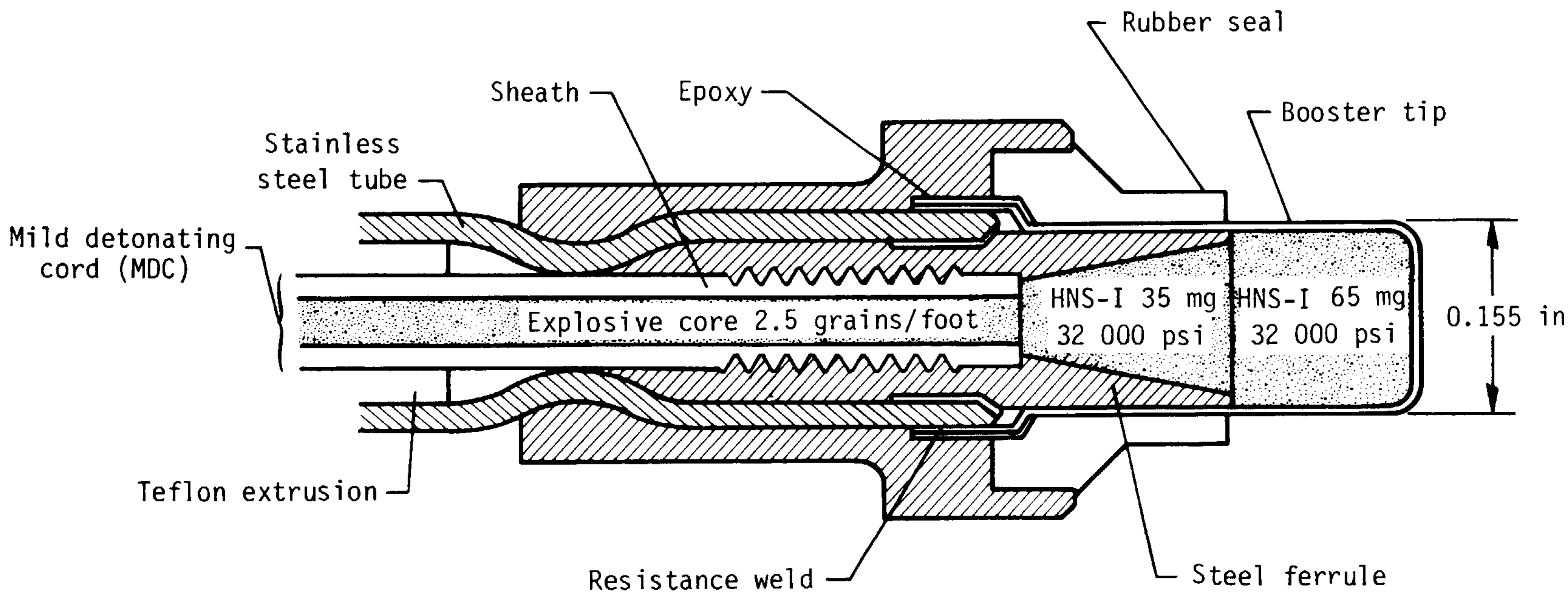
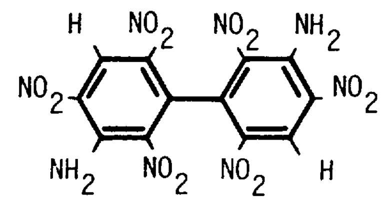
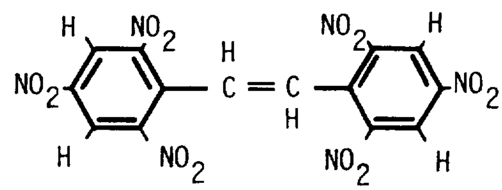


Figure 1.- Cross section of rigid explosive transfer line (1 grain = 65 mg).

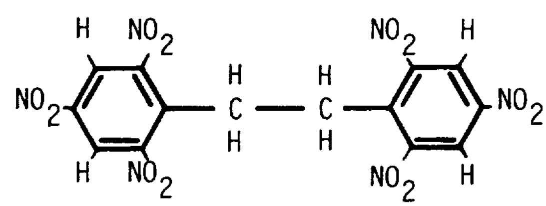
DIPAM
Dipicramide
Molecular weight = 454



HNS
2,2',4,4',6,6'-Hexanitrostilbene
Molecular weight = 450

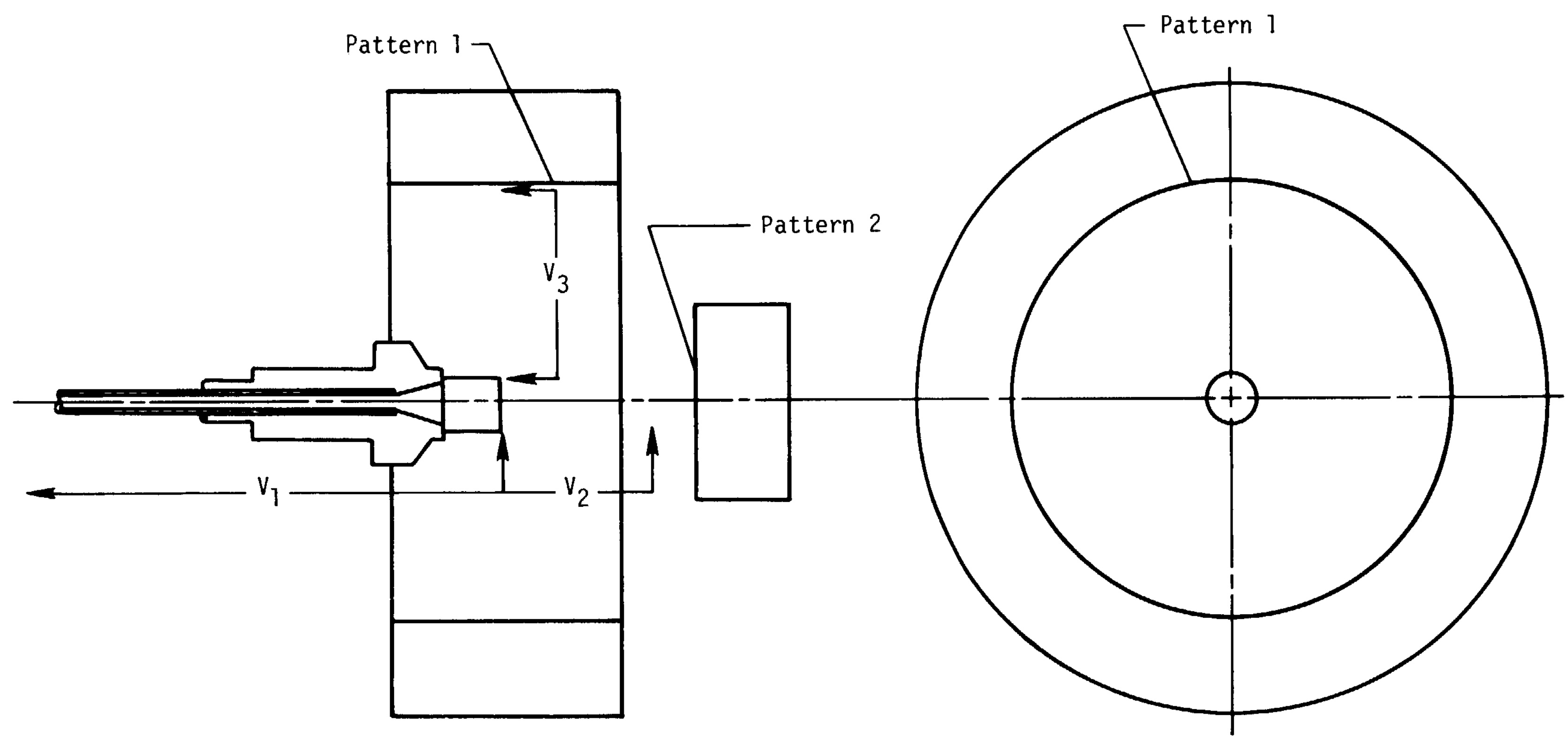


HNBiB
2,2',4,4',6,6'-Hexanitrobibenzyl,
dipicrylethane
Molecular weight = 452



Compound	Melting point
DIPAM	$583^{\circ}F$
HNS-I	$601^{\circ}F$
HNS-II	$604^{\circ}F$
HNBiB	$424^{\circ}F$

Figure 2.- Chemical structures and melting points of explosives in rigid explosive transfer lines.



- V_1 - Line detonation transfer velocity
- V_2 - Axial tip fragment velocity
- V_3 - Side tip fragment velocity
- Pattern 1 - Radial fragment pattern in acrylic
- Pattern 2 - End fragment pattern in acrylic

Figure 3.- Schematic diagram of velocity test fixture.

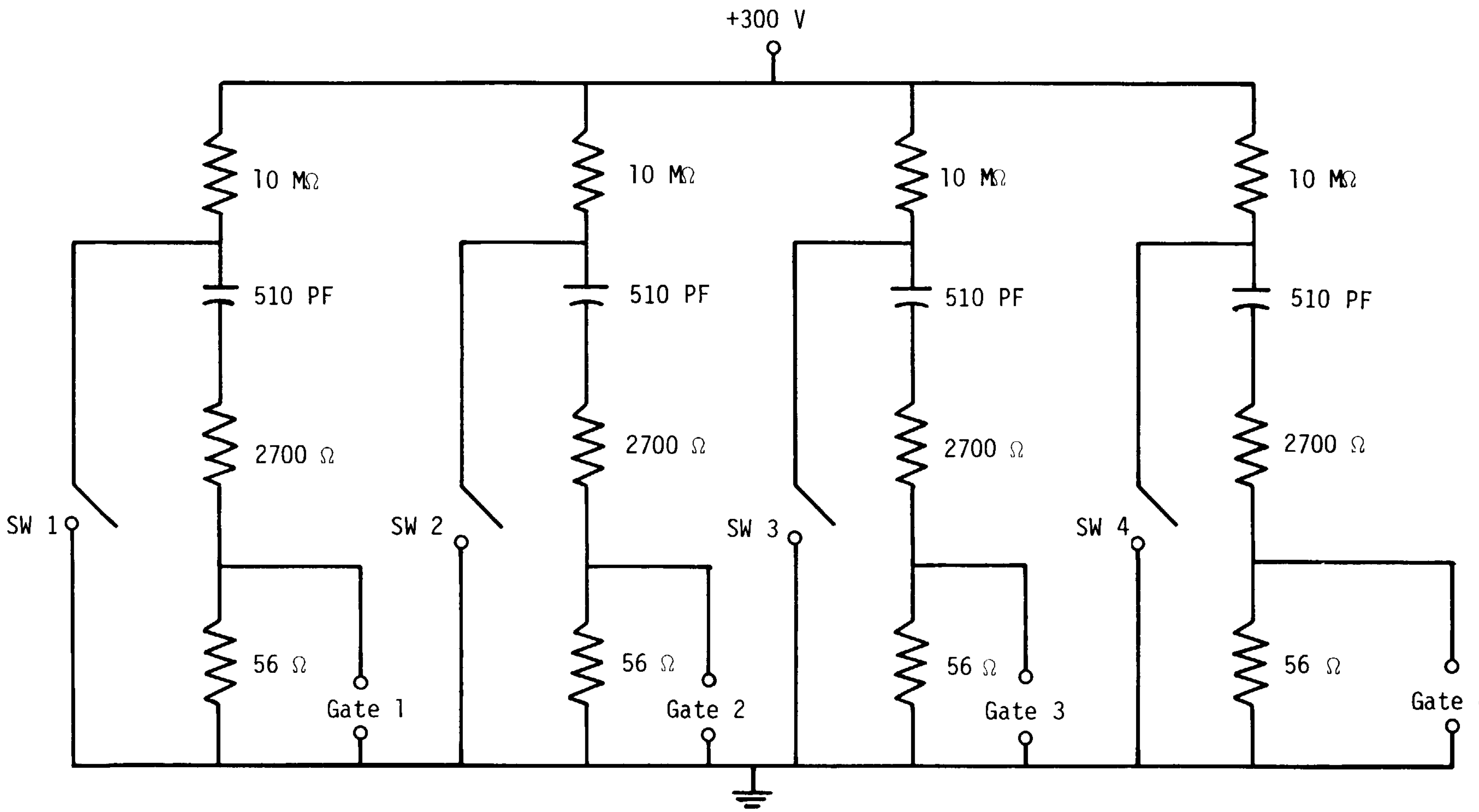


Figure 4.- Velocity-monitor gating circuit. Switches are wire or foil "make" switches.

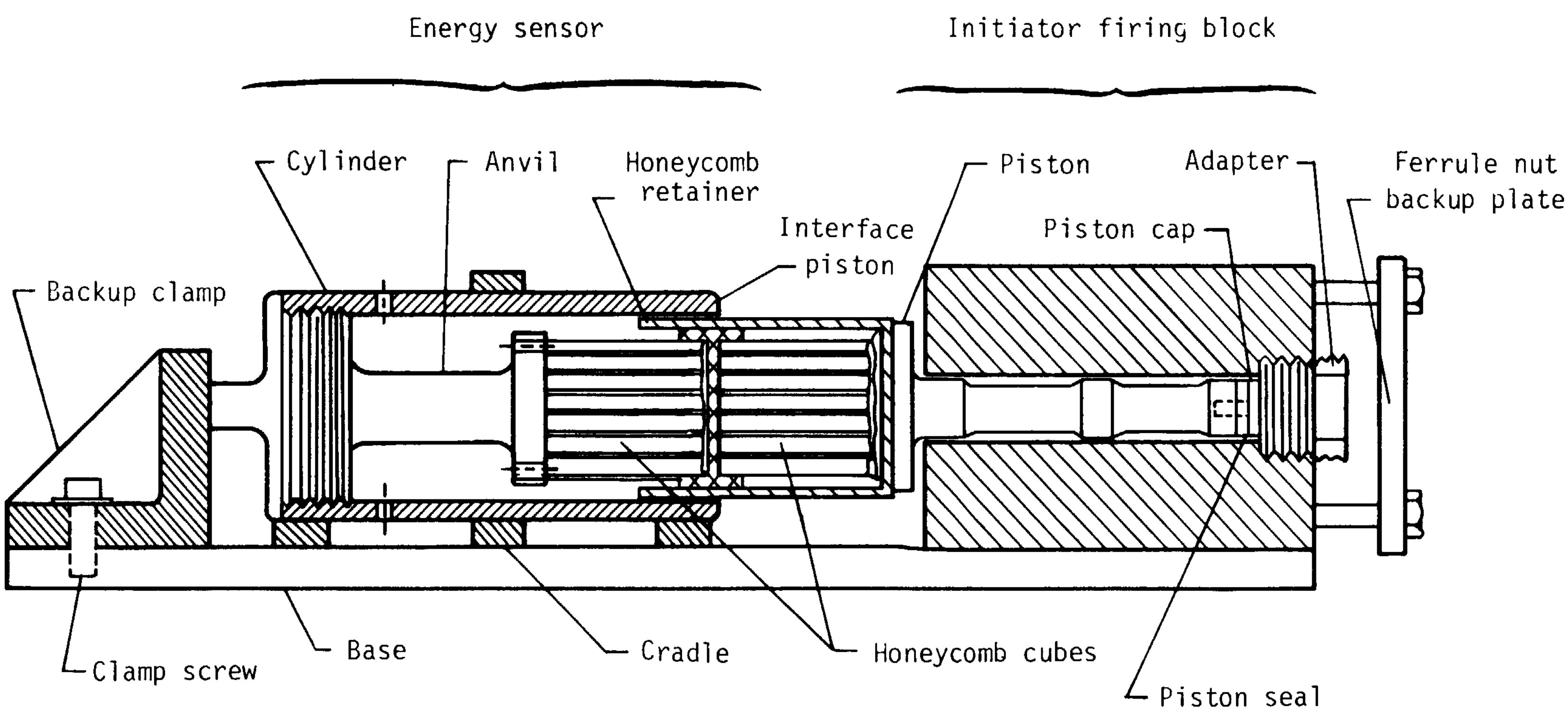


Figure 5.- Energy output test fixture.

Isocratic elution
Detector wavelength: 254 nm
Mobile phase: methanol:water (50:50, by volume)
Flow rate: 2.0 ml/min
Scale: 0.05 absorbance units full scale
Sample size: 5 µl
Chart speed: 0.5 cm/min
Sample solvent: DMSO
R_t: retention time at max. peak height, minutes
T_0: test start

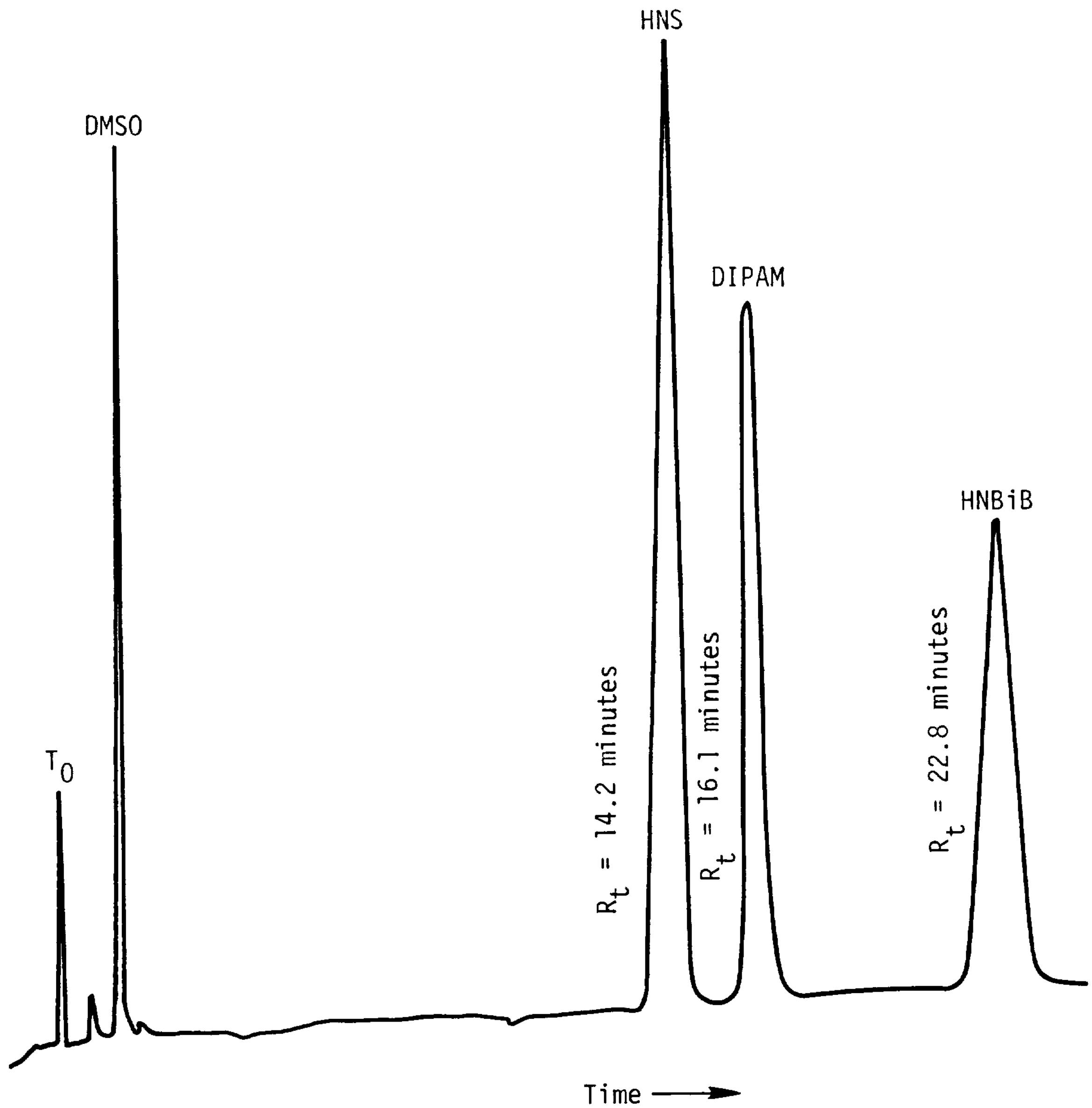
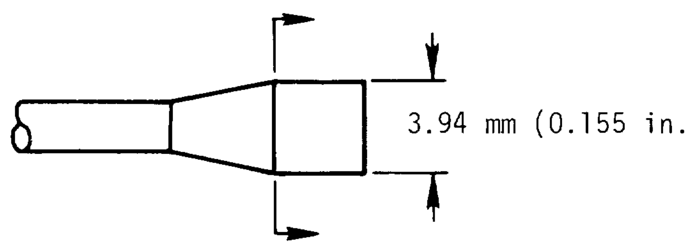
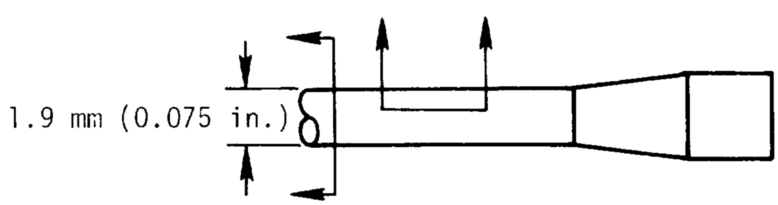


Figure 6.- HPLC chromatogram of HNS, HNBiB, and DIPAM.



(a) Booster tip.



(b) Transfer line.

Figure 7.- Dissection sites used for photographic and chemical analyses.

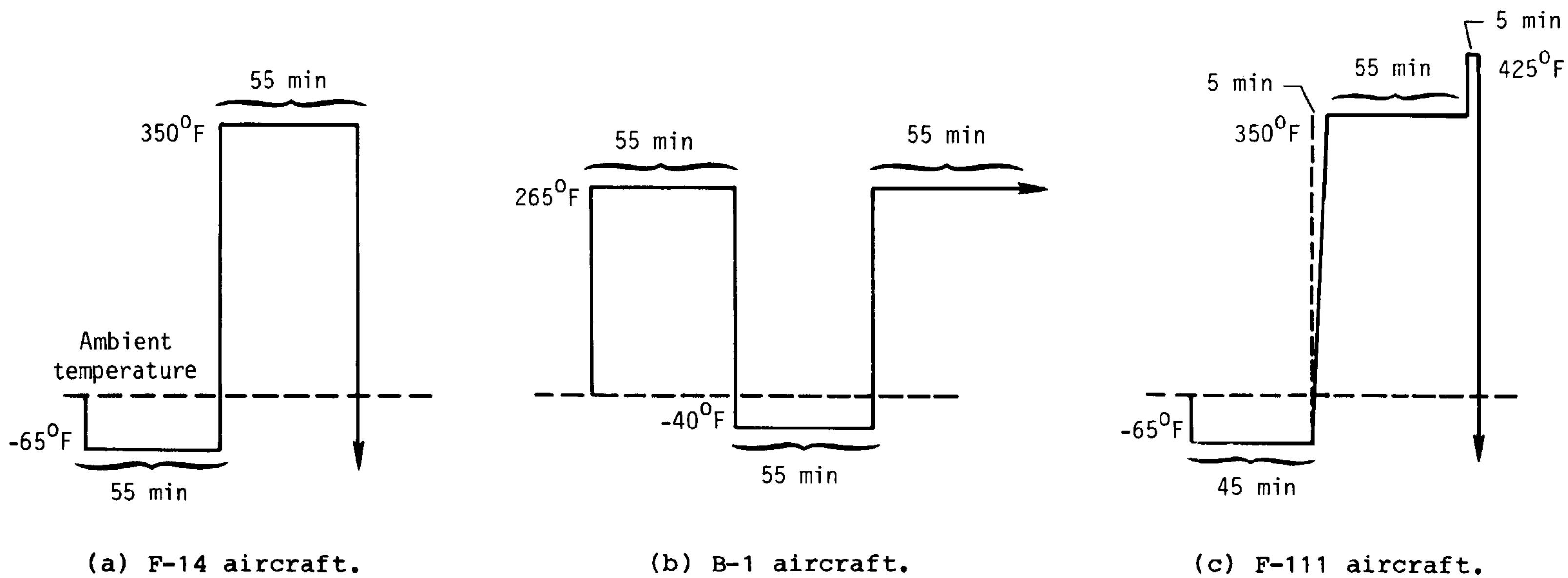
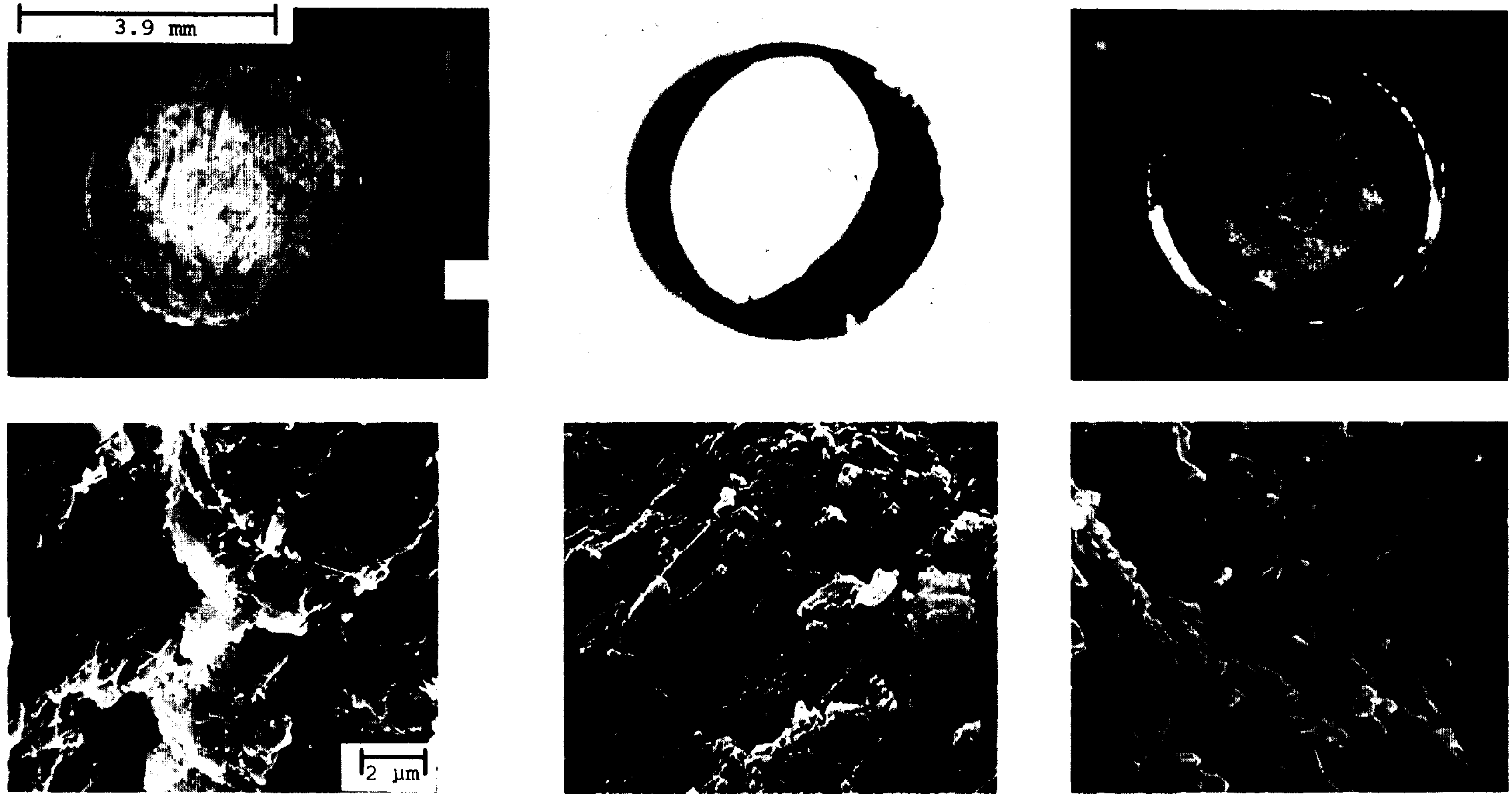


Figure 8.- Temperature/time cycles (100 each) required for thermal qualification of rigid explosive transfer lines.

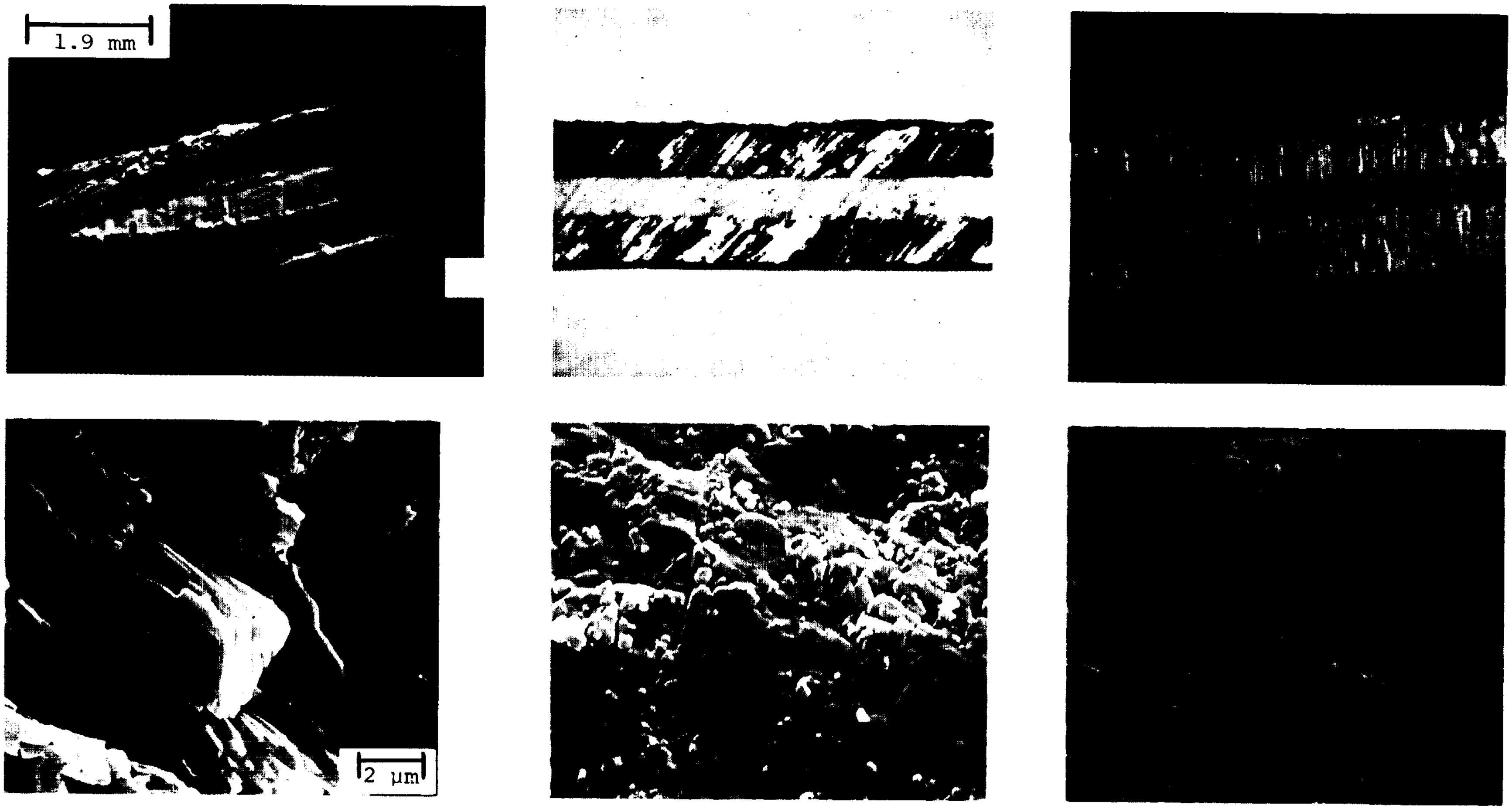


(a) 99.8% (by wt) HNS-I/HNBiB;
no service;
3 years total age.

(b) 98.0% (by wt) HNS-I/HNBiB;
4.7 years total service;
5.1 years total age.

(c) 93.7% (by wt) HNS-I/HNBiB;
no service;
3 years total age;
400°F for 50 hr. L-83-39

Figure 9.- Macrophotographs (upper row) and scanning electron micrographs (lower row) of typical samples of AH-1S booster tip explosive.



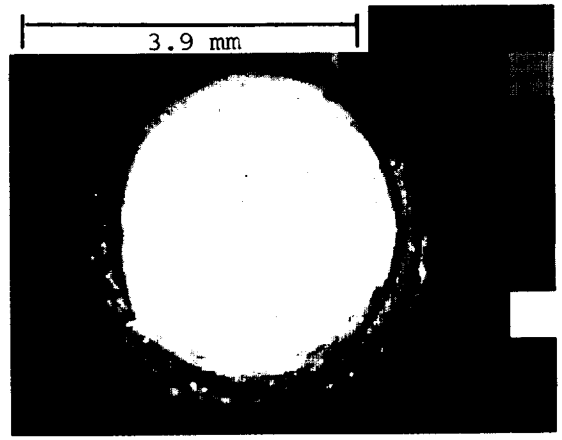
(a) 97.0% (by wt) HNS-II/HNBiB;
no service;
3 years total age.

(b) 99.8% (by wt) HNS-II/HNBiB;
4.7 years total service;
5.1 years total age.

(c) 88.1% (by wt) HNS-II/HNBiB;
no service;
3 years total age;
400°F for 50 hr.

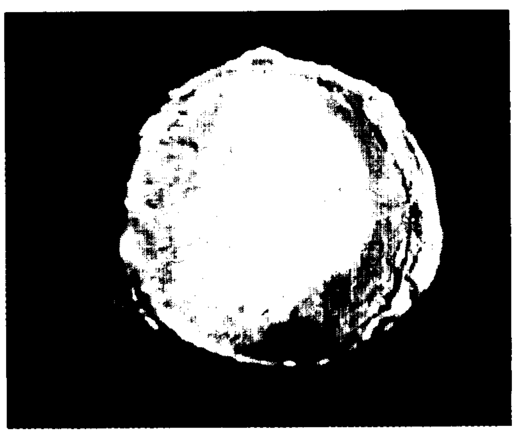
L-83-40

Figure 10.- Macrophotographs (upper row) and scanning electron micrographs (lower row) of typical samples of AH-1S transfer line explosive.

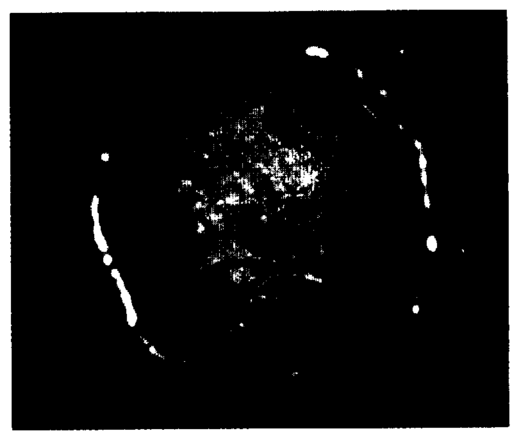


(a) 98.6% (by wt) HNS-I/HNBiB.

(b) 95.7% (by wt) HNS-I/HNBiB; repeat thermal qualification (200°F for 72 hr).



(c) 98.3% (by wt) HNS-I/HNBiB; 375°F for 50 hr.

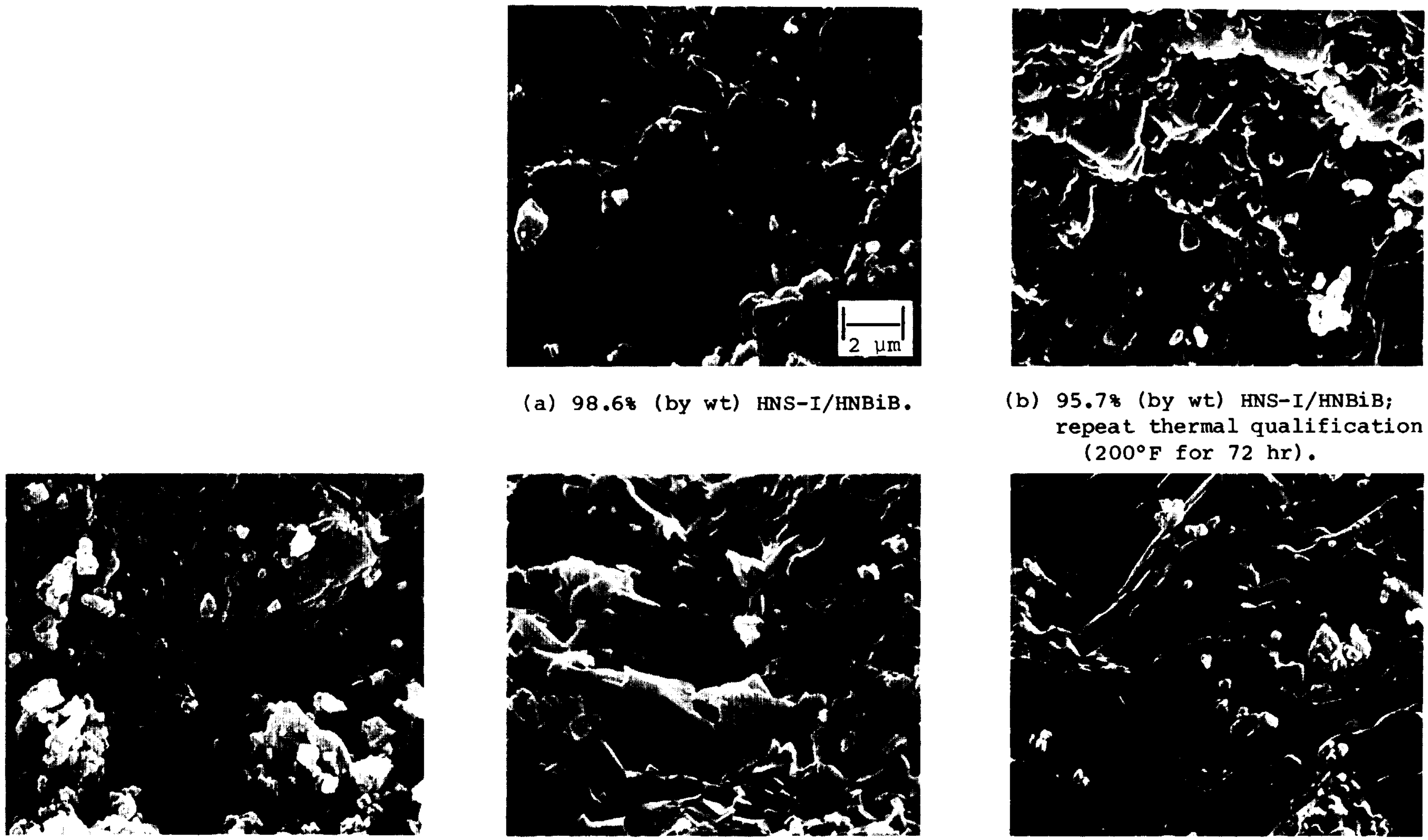


(d) 94.3% (by wt) HNS-I/HNBiB; 400°F for 50 hr.

(e) 91.8% (by wt) HNS-I/HNBiB; 425°F for 50 hr.

L-83-41

Figure 11.- Macrophotographs of typical samples of AH-1G booster tip explosive. All lines have 5 to 7 years total service and are 8 years old.



(a) 98.6% (by wt) HNS-I/HNBiB.

(b) 95.7% (by wt) HNS-I/HNBiB; repeat thermal qualification (200°F for 72 hr).

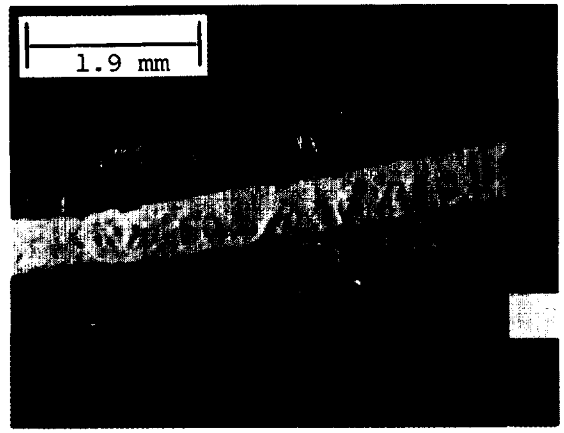
(c) 98.3% (by wt) HNS-I/HNBiB; 375°F for 50 hr.

(d) 94.3% (by wt) HNS-I/HNBiB; 400°F for 50 hr.

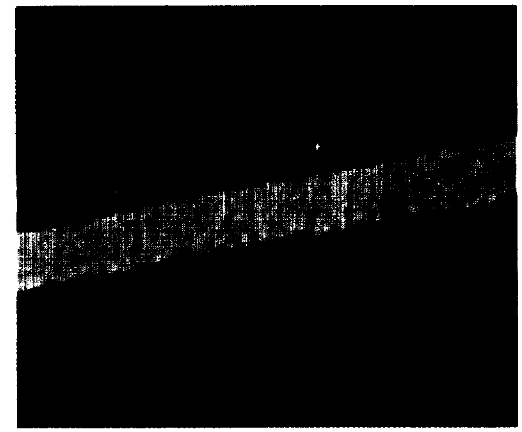
(e) 91.8% (by wt) HNS-I/HNBiB; 425°F for 50 hr.

L-83-42

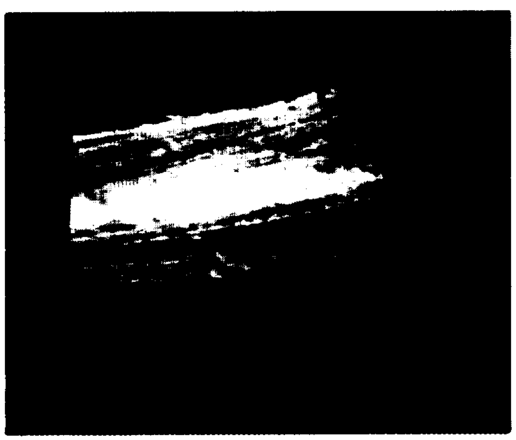
Figure 12.- Scanning electron micrographs of typical samples of AH-1G booster tip explosive. All lines have 5 to 7 years total service and are 8 years old.



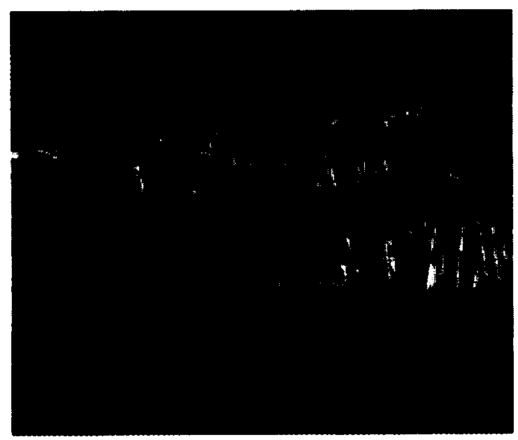
(a) 97.1% (by wt) HNS-II/HNBiB.



(b) 94.5% (by wt) HNS-II/HNBiB; repeat thermal qualification (200°F for 72 hr).



(c) 98.0% (by wt) HNS-II/HNBiB; 375°F for 50 hr.

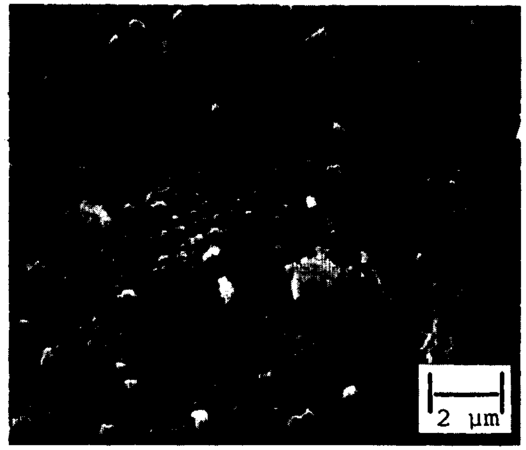


(d) 82.2% (by wt) HNS-II/HNBiB; 400°F for 50 hr.

(e) 21.7% (by wt) HNS-II/HNBiB; 425°F for 50 hr.

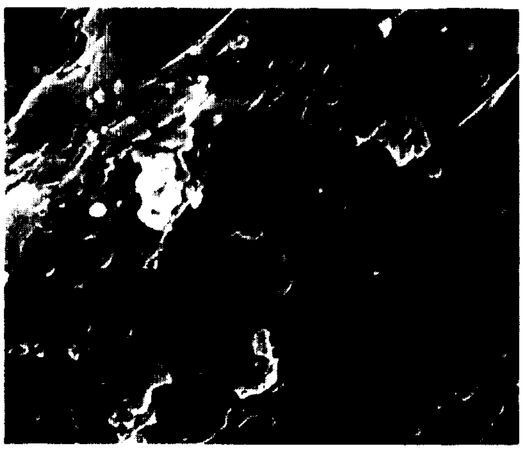
L-83-43

Figure 13.- Macrophotographs of typical samples of AH-1G transfer line explosive. All lines have 5 to 7 years total service and are 8 years old.

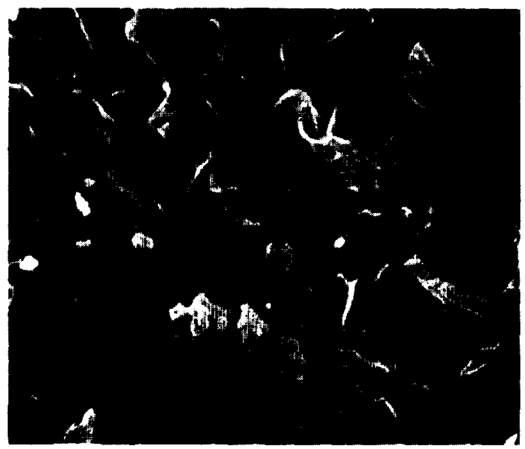


(a) 97.1% (by wt) HNS-II/HNBiB.

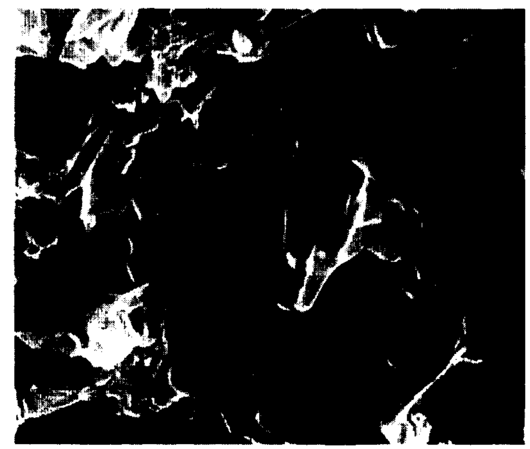
(b) 94.5% (by wt) HNS-II/HNBiB; repeat thermal qualification (200°F for 72 hr).



(c) 98.0% (by wt) HNS-II/HNBiB; 375°F for 50 hr.



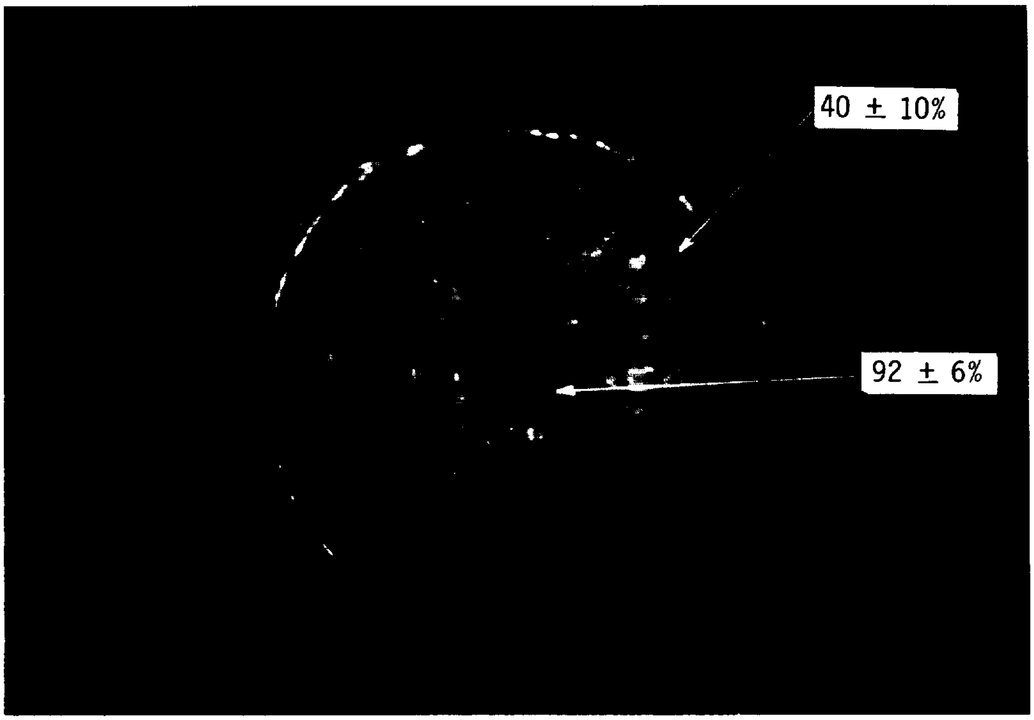
(d) 82.2% (by wt) HNS-II/HNBiB; 400°F for 50 hr.



(e) 21.7% (by wt) HNS-II/HNBiB; 425°F for 50 hr.

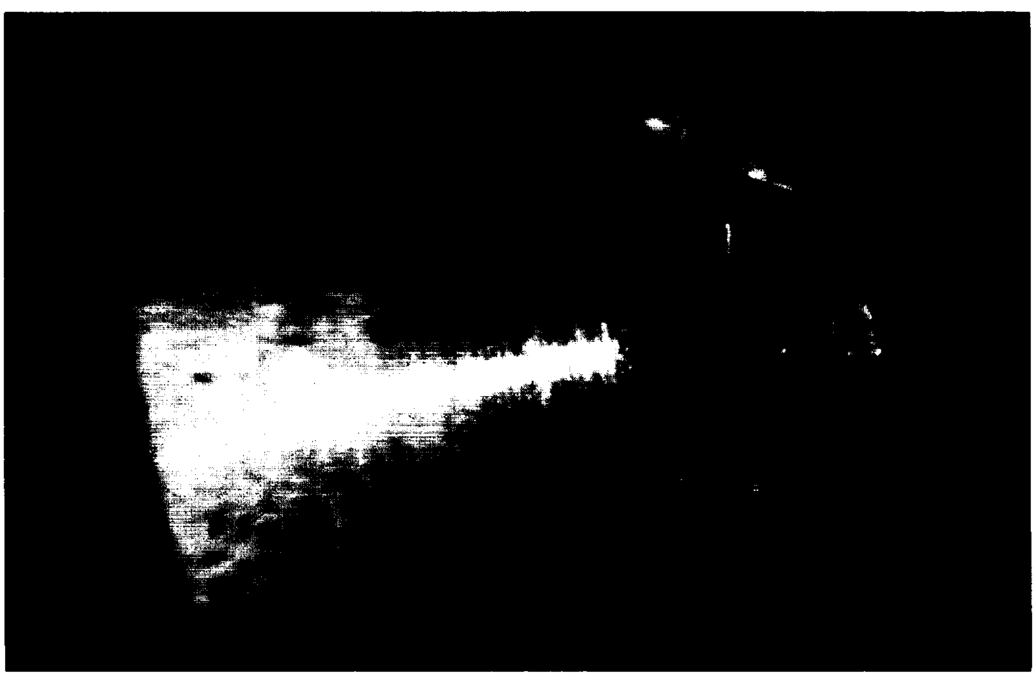
L-83-44

Figure 14.- Scanning electron micrographs of typical samples of AH-1G transfer line explosive. All lines have 5 to 7 years total service and are 8 years old.



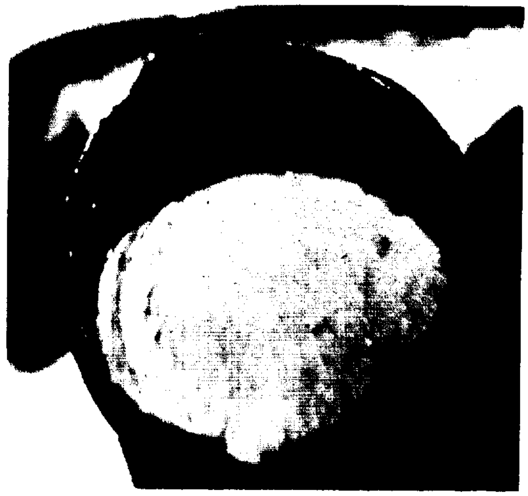
L-83-45

Figure 15.- Internal end view of a booster tip removed from a transfer line exposed to 425°F for 50 hr. Percentages are explosive remaining by weight.



L-83-46

Figure 16.- Side view of ferrule charge removed from a transfer line exposed to 425°F for 50 hr.

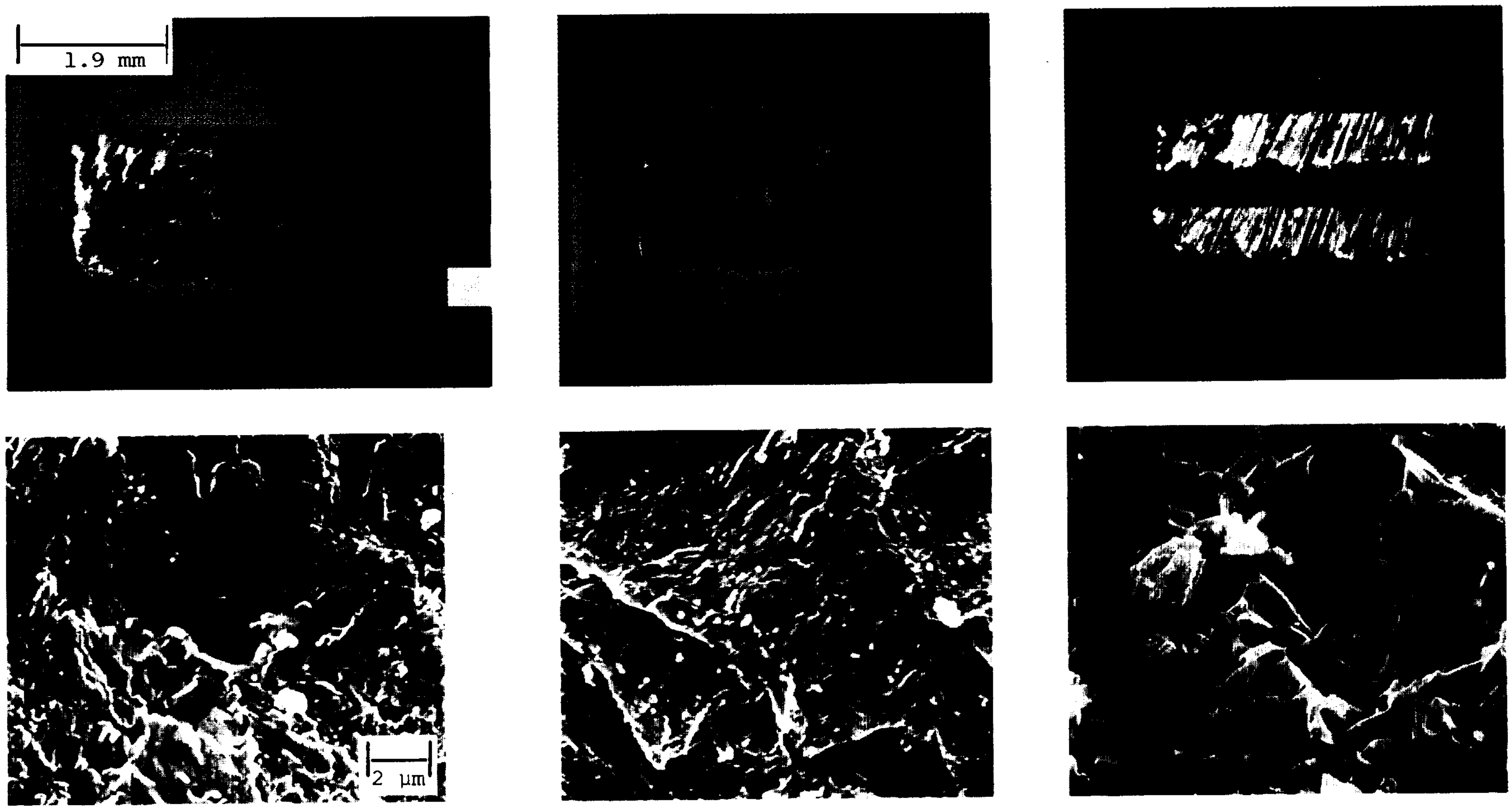


(a) Manufacture date - 7/72;
95.8 ± 0.1% HNS-I;
3.8 ± 1.6% HNBiB.

(b) Manufacture date - 2/75;
99.4 ± 0.2% HNS-I;
0.8 ± 0.1% HNBiB.

L-83-47

Figure 17.- Internal end views of F-14 booster tips removed from transfer lines having 3 years of service.



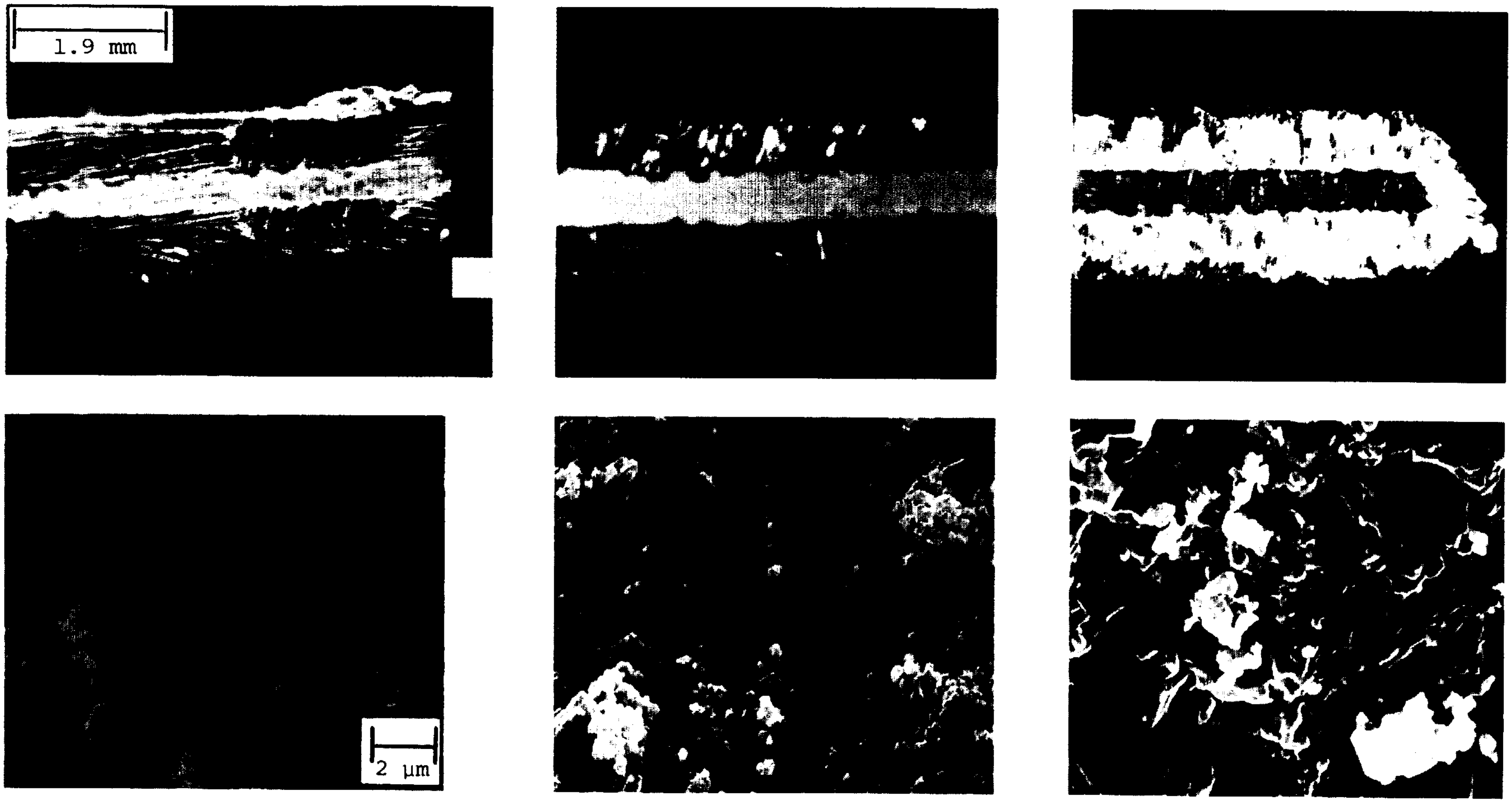
(a) 100% (by wt) HNS-II/HNBiB;
6.5 years total age.

(b) 99.9% (by wt) HNS-II/HNBiB;
9 years total age.

(c) 56.3% (by wt) HNS-II/HNBiB;
6.5 years total age;
425°F for 50 hr.

L-83-48

Figure 18.- Macrophotographs (upper row) and scanning electron micrographs (lower row) of typical samples of F-14 transfer line explosive. All lines have 3 years total service.



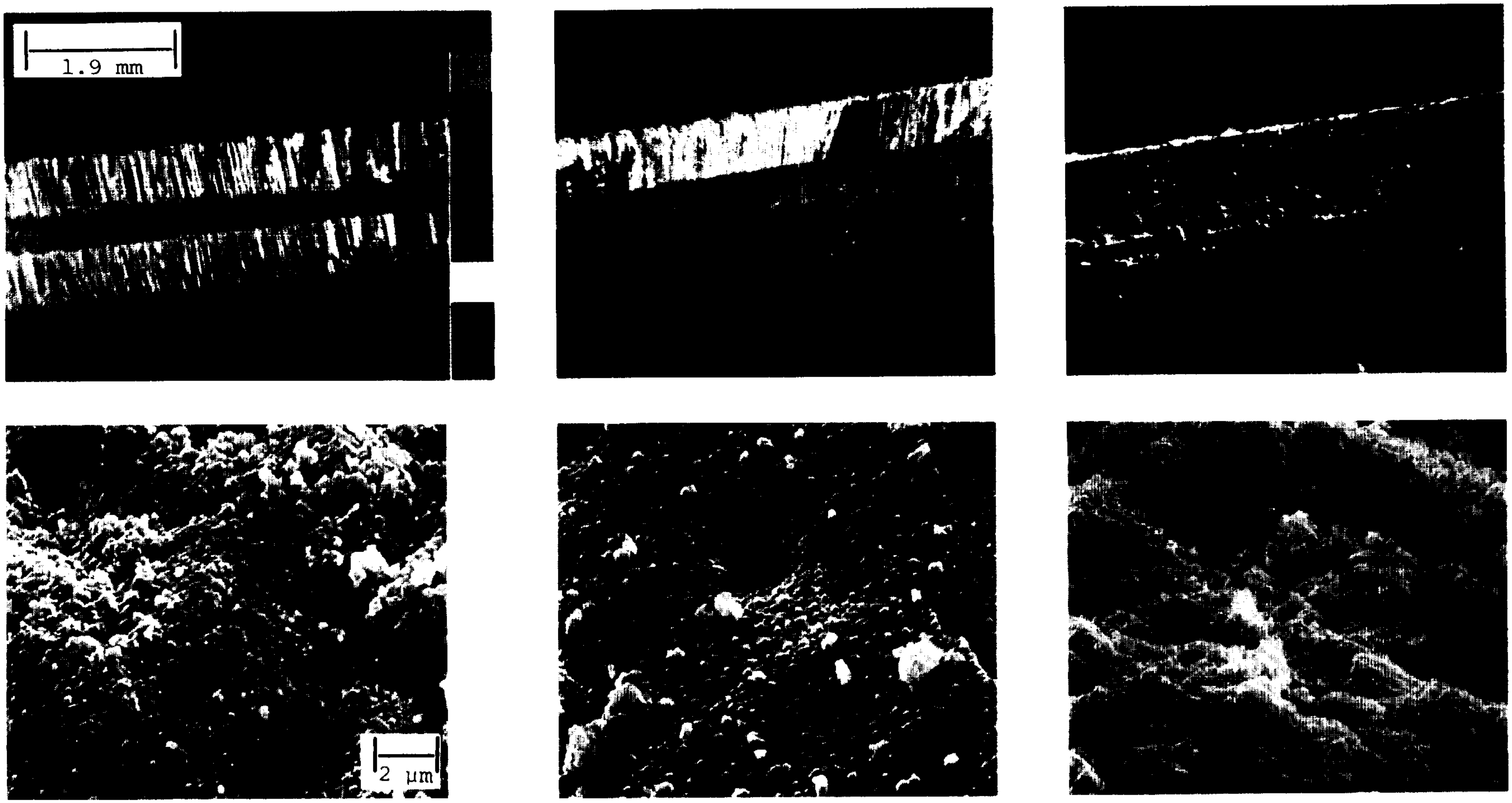
(a) 97.0% (by wt) HNS-II/HNBiB;
3 years service;
3.5 years total age.

(b) 95.7% (by wt) HNS-II/HNBiB;
no service;
7 years total age.

(c) 88.35% (by wt) HNS-II/HNBiB;
3 years service;
3.5 years total age;
425°F for 50 hr.

L-83-49

Figure 19.- Macrophotographs (upper row) and scanning electron micrographs (lower row) of typical samples of B-1 transfer line explosive.



(a) 100.9% (by wt) DIPAM;
5.5 years total age.

(b) 97.4% (by wt) DIPAM;
8.5 years total age.

(c) 100.3% (by wt) DIPAM;
5.5 years total age;
450°F for 50 hr.

L-83-50

Figure 20.- Macrophotographs (upper row) and scanning electron micrographs (lower row) of typical samples of F-111 transfer line explosive. All lines have 4 years total service.

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15. Supplementary Notes

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Eleonore G. Kayser: Naval Surface Weapons Center - White Oak, Silver Spring, Maryland.
Morry L. Schimmel: McDonnell Aircraft Company, St. Louis, Missouri.

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16. Abstract

This paper describes a joint Army/NASA-sponsored research program on the service life evaluation of rigid explosive transfer lines. These transfer lines are used to initiate emergency crew escape functions on a wide variety of military and NASA aircraft. The purpose of this program was to determine quantitatively the effects of service, age, and degradation on rigid explosive transfer lines to allow responsible, conservative, service life determinations. More than 800 transfer lines were removed from the U.S. Army AH-1G and AH-1S, the U.S. Air Force B-1 and F-111, and the U.S. Navy F-14 aircraft for testing. The results indicated that the lines were not adversely affected by age, service, or a repeat of the thermal qualification tests on full-service lines. Extension of the service life of rigid explosive transfer lines should be considered, since considerable cost savings could be realized with no measurable decrease in system reliability.

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